VaMEx - LAOLa - Valles Marineris Exploration Lokales Ad-hoc Ortungs- und Landesystem

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Abstract: The DLR Space Agency studies how to explore the Valles Marineris on planet Mars. The interest in this area arises since the area is poorly investigated. This is due to the harsh topology in this region with deep canyons and high mountains, making it even more interesting for scientist.
The mission concept foresees the use of a swarm of multiple UAVs (Unmanned Aerial Vehicle) and UGVs (Unmanned Ground Vehicle) that will be brought in a lander. All swarm members act in a cooperative way, i.e. some members explore the terrain and telling other members, where an interesting feature can be found.
Very important subsystems of this mission are the location determination system and the communication system, which are subject of VaMEx-LAOLa, a project funded by the DLR- agency (FKZ: 50NA1527). The position determination is realized in two steps. The relative position between all members will be determined ad-hoc from exploration start using radio waves. The global position and orientation is analyzed in a later mission phase by use of a star camera. The communication system will establish a data link between all swarm members.
Within this paper, the technical implementation and status of LAOLa is presented.

1. INTRODUCTION

The VaMEx mission is a visionary approach to find water on mars. It is including many topics, never realized in a space mission till now. One of these approaches is the use of an autonomous swarm concept with flying, crawling and rolling members. In order to realize this mission, many new subsystems need to be developed and tested.

The LAOLa project is focused on two subsystems, holding a key role for a distributed mission, i.e. the position determination of each swarm member and the communication between all members. Since LAOLa is a demonstration project, all hardware used is not space qualified. Furthermore the project objective is to show the feasibility of the concept used. Therefor at the end of LAOLa, a demonstration of the developed systems in an outdoor demonstration on earth is scheduled.

In the following chapters the position determination and the communication system will be explained in detail.

2. POSITION DETERMINATION SYSTEM

A local position is referenced relative to other swarm members only. There is no information about the orientation (i.e. north direction) or absolute position on the mars (or any other planet). The local position is necessary for coordination between swarm members, to find the way back to the lander or to find points of interest (POI). The resolution of the local reference frame is higher than that of the global reference frame. A global position is an absolute position on a planet (longitude, latitude, height above sea level). It is necessary for planning future missions, for mapping and most important, for aligning high gain antennas towards the orbiter or even to earth.

Both reference frames can be transferred into each other, once their orientation and relative position is known.

2.1 Local reference frame

The idea is to build up an ad-hoc real time location determination system (RTLS), even before the lander will touch the surface. For this, the lander will eject several radio transponders that will build up a reference frame once they landed on the surface. Thus the lander position can be analyzed during the landing procedure.

For the following mission phase, these transponders will serve as reference also for the UAVs and UGVs.

2.1.1 Hardware

In order to obtain the before explained performance, the position of the radio transponders must be identified from the lander. To achieve this, the distance as well as the direction to each transponder will be measured. These features can be provided by a radar system on board of the lander. In this case a Frequency Modulated Continuous Wave (FMCW) secondary radar includes all necessary features.

In a secondary radar, the emitted radar signal is received and actively repeated by the transponders. Additionally, the transponder can modulate the backscattered signal, enabling the identification of each transponder. The FMCW radar can measure the distance by the frequency shift between sent and received signal of the modulated signal. The direction of the received signal is determined with the help of an antenna array and the phase difference.

Distance and angle between radars can also be measured. There will be one radar system on each swarm member.

Within this project an FMCW - secondary radar will be developed by the LHFT of the University Erlangen. (Accuracy: distance 5cm RMS, angle 2° RMS; range: radar to radar: 200m, radar to transponder: 20m)

Since the radar development is still in progress, first software tests were realized using the commercial of the shelf ultra-wide-band transceiver DWM1000 by DecaWave. This module allows the distance measurement between two nodes, but no direction measurement. The distance is measured by the time of flight of the signal. For this, there is a clock on each DWM1000, running at 64GHz. The reception time and the transmission time can be determined with this clock. An improved method for the distance measurement is the double sided two way ranging (DS-TWR), allowing a ranging precision of +-5cm using DWM1000. [1]

2.1.2 Software

The software is in charge of fusing all available information in order to calculate the 3D Cartesian coordinates of each swarm member.

In case of the preliminary tests using DecaWave's ultra wideband modules, the only available informations are distances between the members. The 3D position is defined, once there are three distances to other members that are not arranged within a plane. The distance between two members was measured by a DS-TWR, represented in figure 1.

Since a simultaneous acquisition of all distances is not possible with these modules, they are acquired sequential.

The process of arranging the member positions in a constellation, where the distances between them represent the measured distances, is called multidimensional scaling (MDS). It is an iterative method, moving each member position (virtually) and trying to minimize an optimization factor, called loss. The loss is defined by equation 1.

The loss represents an indicator for the quality of the solution.

$d_{i,j}$: measured distance between member i and j (1)
p_i and p_j: calculated positions

The optimization was initially based on a gradient decent algorithm, following the negative derivation of the loss in x, y and z. The disadvantage of this method is the possibility of ending up in a local minimum, which will lead to a total fault of the constellation determination. This is critical at the first measurement, when there is no historical data. Once there is a correct constellation determined, it will be used as input for the next iteration, making a total fault unlikely.

An improved optimization method is described in [2]. Here the result will always represent a global minimum. The implementation of this method is just in process.

Once the radar sensor of LHFT is available, it will deliver not only distances between all members, but also the elevation and azimuth angles. Thus, a radar can determine the relative 3D position of all transponders and other radars. The results of the different radars that are mounted on the swarm members can be merged in one constellation, using MDS. And since the angle noise reveals in a growing position uncertainty with higher distances, MDS will improve the position accuracy, compared to the raw radar information.

2.2 Global reference frame

At exploration start the global position of the swarm on the surface of mars is unknown. And since there is no magnetic field on mars, also the orientation is unknown. In order to figure out both, the idea is to bring a star tracker on mars. The orientation can directly be derived by the star constellation. In combination with an accelerometer and the point of time, the global position can be calculated. The methods used are known as celestial navigation.

2.2.1 Hardware

In LAOLa a simple commercial DSLR (Digital Single Lens Reflex) camera is used. It is mounted on a tripod together with an accelerometer. Additionally a commercial star tracker is mounted on that platform. It is used as a reference, delivering right ascension and declination.

The output of a commercial star tracker is not sufficient, since it will only deliver a vector (i.e. defined by right ascension and declination), but not the orientation.

A MEMS Accelerometer will be used, to determine the gravity vector.

2.2.2 Software

The system is connected to a PC, where the data is processed. It starts with taking an image of the night sky at a certain point of time. The software will detect all stars in the image and centralize them in sub pixel precision (centroiding). Then the star pattern will be analyzed (angles and distances) and a search for this specific star pattern in a star catalog is initiated. Once it is found, the direction in which the picture was taken is known. This is the basic idea of all star trackers.

Additionally our algorithm is determining the orientation. For this, the identified stars in the image are used, to calculate the north direction.

The accelerometer will deliver the gravity vector. Since the camera is not moving, an averaging of the gravity vector over a long time period will improve the result.

Since now, there are three known vectors, the time and the knowledge, to be on the mars surface. The attitude of mars must be derived by the time stamp that was saved, when taking the image. Using these inputs, the position, i.e. the longitude and latitude on mars can be calculated. Since all vectors are defined in one coordinate system, they can be combined on one point on the surface, as illustrated in figure 2.

The accuracy of the calculated position is mainly influenced by the quality of the measured vectors. By default, the error of the accelerometer holds the major part. An angle error of 0.5°, reveals in a position error of 30 km on Mars. Measurements, revealing the achievable position accuracy using a COTS MEMS accelerometer, are planned as the next step, after the software implementation is finished.

3. COMMUNICATION

The radio communication system will provide passing of message between all nodes. It should be self-configuring without a central controlling node. To increase robustness it is kept simple and mesh-networking is not supported in the first approach.

3.1 Hardware

Although communication between the nodes could be done with the DecaWave module, another approach was selected, because communication should not interfere with the range measurement performed on the DecaWave. The DecaWave cannot do range measurement and data transmission reliably at the same time. To avoid additional arbitration, a simple 2,4GHz transceiver (nRF24L01+) was used to have an independent channel for data transmission. Furthermore the continuously running range measurement already takes a significant amount of bandwidth.

The range of the 2,4GHz-Module is sufficient for the demonstration mission. Later, on a mars mission, it can be easily replaced with a more powerful transmitter in a different band, which is not limited by regulations in place on earth. The maximum data rate is 2 Mbit/s, which should be enough for the demonstration mission.

3.2 Software

The transceiver does not have any means for collision management or addressing, therefor this must be implemented in the software. For this we use our in-house developed CAPRI-Protocol [3].

CAPRI does collision avoidance by assigning a time slot to every node in the network. The network is organized as ad-hoc network without a dedicated master node, so it does not have a single point of failure. When nodes fail or new node appear, the network reconfigures its self automatically. Nodes that do not require the full length of their time slot for transmission may give up their slot in the current cycle, so the next node can use it. This improves throughput and network utilization. The time slots also give determinism and real-time capabilities to the transmission.

Figure 3 show the transmission cycles of CAPRI. On startup, when no network is formed, the “hello cycle” is active. Nodes discover each other with a classic CSMA/CD method. After that an order is negotiated in the “reordering cycle”. When the network is formed and stable the “Normal Cycle” is active and nodes transmit after each other without collisions. New nodes can register themselves in the µSlots after each cycle. On network changes, e.g. nodes gone offline, a new reordering cycle may happen.

4. REFERENCES

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