27/28th International Conference
ENGINEERING MECHANICS 2022
Milovy, Czech Republic, May 9 –12, 2022
Paper **#41**, pp. 225–228, doi: 10.21495/51-2-225

DETERMINATION OF CURRENT FLOOR DURING MOBILE ROBOT ELEVATOR RIDE

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Abstract: *In order for the mobile robot to use the elevator, it must be capable to call the elevator in, detect the control panel, select desired floor and to determine what floor is the elevator located. The paper deals with determination of correct floor the mobile robot is currently at using the processing of onboard accelerometer data. Up to 5 relative floor difference the method exhibits over 95% accuracy.*

Keywords: Mobile robot, Elevator floor determination, Signal processing, Measurement.

1. Introduction

Mobile robots for indoor environment are commonly not equipped with locomotion that enables to handle stairs, however, they are perfectly capable to use the elevator when available. In order to use the elevator, the robot must be able to call the elevator in, detect the control panel and select desired floor. Moreover, it must be able to determine what floor is the elevator currently located when stopping, in order to leave in the correct floor. This subproblem is the issue we are trying to resolve in this paper.

The task of riding the mobile robot in the elevator is commonly solved in particular environment. The methods include usage of convolution neural networks (CNN), as stated in Wang et al. (2019), where the CNN classifies the floor from the image of the view acquired by the robot when elevator doors are open. While the method reaches 93-97% success rate, it suffers from not being universal, as the network must be trained on particular building and also suffers when there are changes in the environment.

Another approach uses the processing of images of elevator display. Abdulla et al. (2016) uses markers to find region of interest in acquired images and uses optical character recognition methods to determine the current floor. Similar approach with feature extractor by histogram of oriented gradients and bag-of-words that are further fed into neural networks is used by Islam et al. (2017). Both methods have high values of success rate (99%), however, similarly to previous work are used on particular elevator. Solely CNN approach using YOLO system was used by Kim et al. (2020), reaching about 80% success rate.

Different approach is taken by Li et al. (2018), that utilizes fusion of several sensor, including barometric one together with wireless access point (AP) received signal strength. While this method is very robust, it requires known position of APs, that must be installed prior to the application.

We decided to use a slightly different approach, using the data from accelerometer to resolve the issue of floor determination. While we intend to fuse accelerometer data with visual information from the elevator info screen, there are some elevators not equipped with those. Therefore this paper only deals with the accelerometer based detection.

2. Materials and methods

The accelerometer measures the acceleration of the robot. We assume that in the elevator the robot is static relative to the elevator and the accelerometer is firmly attached to the robot, oriented parallel to the

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robot base and therefore to the elevator floor. Thus, while 3D accelerometer is used, only single axis measurement is taken into account.

The robot used for experiments was mobile robot Breach, equipped with IMU measuring unit MPU 9250 by Bolder Flight Systems, that contains 3D accelerometer, 3D gyro, magnetometer and thermometer. Module is connected with Arduino NANO PCB that handles data acquisition and communicates with the robot main onboard computer.

The accelerometer has a range of ±4g, maximum sampling frequency is 1.1kHz. Sampling frequency in all measurements was set to 100Hz.

Prior to entering the elevator, the robot is stopped and accelerometer is calibrated by measuring the gravitational acceleration for short time period. The mean of the measurement is then subtracted from the further measurement to reset the offset of the sensor.

It is not possible to determine the actual floor the elevator stopped at solely from accelerometer measurements. Following assumptions are therefore considered:

1. The floors in the building are of the same height.
2. The robot is aware of its point of entry (the starting floor).

Absolute floor determination solely from accelerometer necessarily suffers from error accumulation, therefore it must be fused with the outside independent information. The goal of accelerometer data processing is to give the relative floor change (signed integer) together with the information that the elevator is stopped. Assumption 1 is required even for such task, however, it was met in all our experiments and is valid in majority of buildings. Assumption 2 is required when relative floor change determination is converted to absolute floor position. Both assumptions are soft ones when fusion with outside information takes place.

Typical course of measured data is shown in Fig. 1, where the elevator first goes 2 floors up and then 2 floors down. One can see quite a bit of noise in the data, with more high frequency noise during the ride caused by the shaking of elevator cabin. However, it is clear that both acceleration and deceleration of the cabin are clearly identifiable; the interesting fact is that the deceleration when stopping from going up and acceleration when starting to move down are very similar in shape, as well as the other pair of maneuvers.

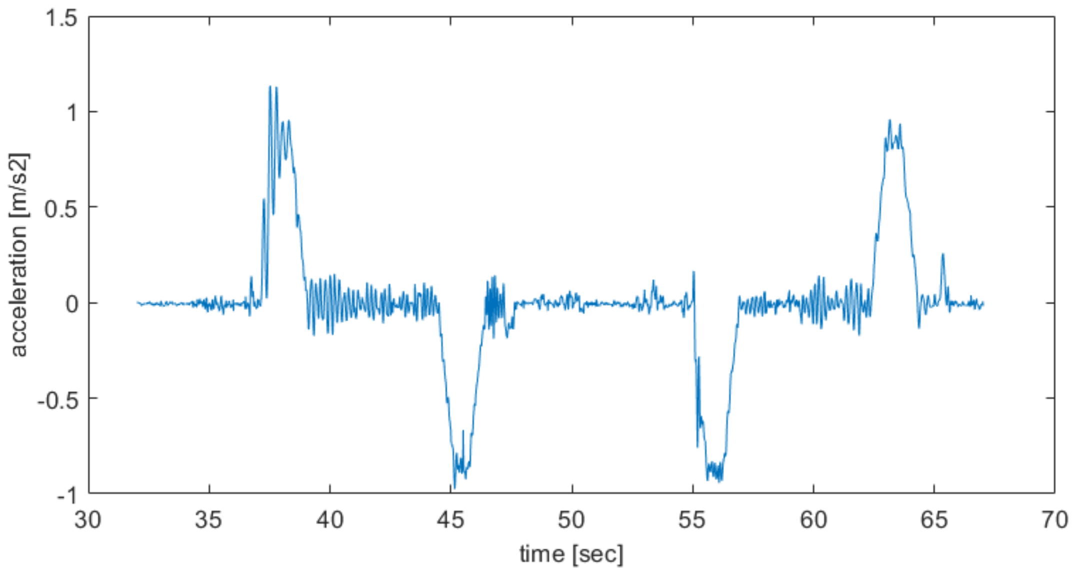

Fig. 1: Typical course of acceleration.

The overall processing diagram is depicted in Fig. 2. As the method should be elevator independent, the first step is the calibration and recording of acceleration patterns. Therefore, the elevator first goes on floor up and down. Recorded data (in general of a similar shape to ones depicted in Fig. 1) define the acceleration patterns further used in finding the start and stop times of elevator motion and double integration gives the estimate of floor height.

The direction of the motion is easily determined either from the sequence of acceleration patterns, that differ for each direction; or using the gravitational acceleration element.

Cross correlation is used to determine the motion time between pairs of acceleration and deceleration. In this timeframe the acceleration is integrated to obtain the velocity, that is reset to zero when elevator cabin is not in motion. Afterwards the updated velocity is integrated once again to obtain the relative distance traveled by the elevator. This number is compared with the floor height and integer number of relative floor change is calculated accordingly.

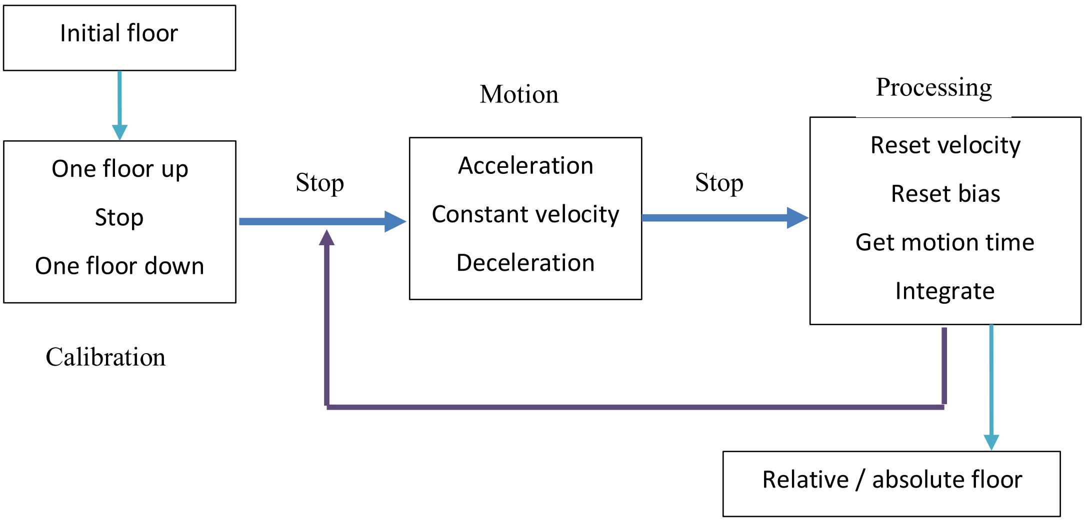

Fig. 2: General flow of the algorithm data and processing.

An example of measured and processed acceleration - velocity courses during multiple floor changes are shown in Fig. 3.

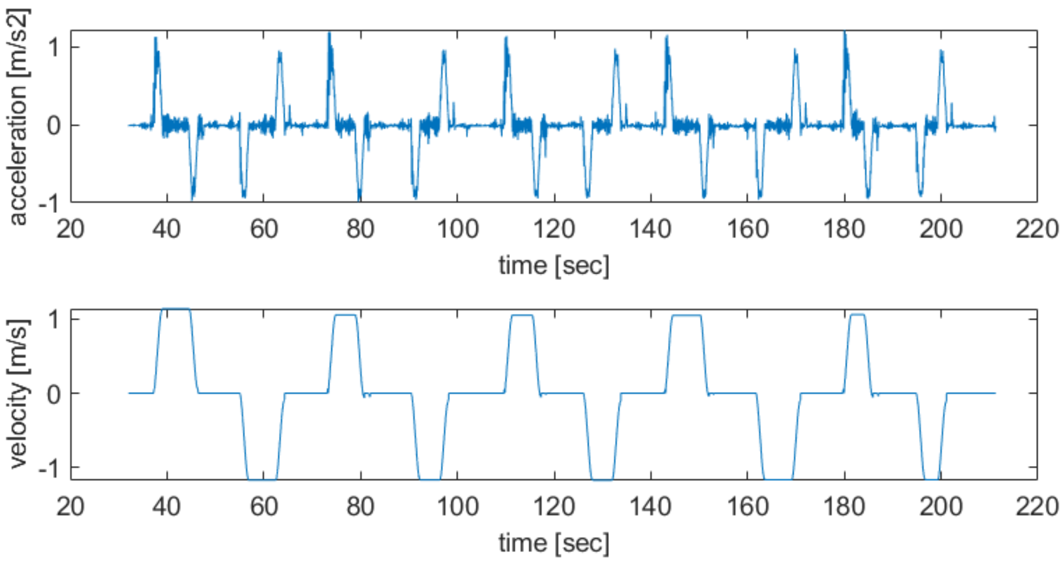

Fig. 3: Acceleration and velocity courses during multiple floor changes in a single elevator ride. Relative floor changes in this example are +3 / -3 / +2 / -2 / +2 / -2 / +2 / -3 / +1 / -1.

In total 17 different elevators were used to gather the data. Majority of them (13) were from 7-floor buildings, 2 were from 10-floors building and 2 from 19-floors building. In all elevators a number of rides with randomly selected direction and floor change were performed, data continuously acquired and processed and ground truth recorded as well.

The data were processed as stated above and further analyzed to determine whether the direction or the load of the elevator plays significant role. Both parameters were found of no significance.

3. Results

In order to fuse determined floor with outside information, some description of result uncertainty is required. Such description is necessary when, e.g., Bayesian based approaches are considered. Therefore, the results are summarized in a table 1 in the form of percentage of correct determination of relative floor change together with corresponding failures percentage with respect to the magnitude of floor change error. In any of experiments the error did not exceed 2 floors, in neither direction.

Results in the table 1 are distinguished by the color of particular floor change, as for the changes 7-10 the number of measurements was smaller, the same to even higher extent holds for changes 10-14.

One can see expected increase of errors with higher distances. Such increase is inevitable, however, the resulting variances can be utilized when outside information is fused (e.g. by image processing of elevator information screen). Interestingly the variances are not symmetrical and tend to higher numbers in negative floor change. The cause is yet to be determined.

Tab. 1: Resulting performance of relative floor determination.

Floor change	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
-2	0	0	0	0	0	0	0	0	0	3.7	0	0	0	0
-1	0	0	0	1.3	2.1	3.1	10.5	12.9	22.2	33.3	14.3	12.5	18.2	60.0
correct	100	100	98.9	97.5	95.9	94.8	84.5	81.5	75.0	59.2	78.6	75	72.7	31.4
1	0	0	1.1	1.2	2.0	2.1	5.0	5.6	2.8	3.8	7.1	6.3	9.01	8.6
2	0	0	0	0	0	0	0	0	0	0	0	6.2	0	0

4. Conclusions

Proposed acceleration data processing offers reliable results for floor changes up to 6. Higher floor changes determination suffers from necessary error accumulation during the change, however, the error never exceeds 2 floors and only rarely exceeded single floor. This gives a very promising outcome for further fusion with outside information as the variances are kept close to the correct floor determination.

Acknowledgement

The results were obtained with institutional support RVO 61388998 of the Institute of Thermomechanics of Czech Academy of Sciences and with support of Mobility Plus Projects with Ministry of Science and Technology of Taiwan and the CAS, project no. MOST-20-06.

The authors would like to thank M. Havelka for his help in data measurement.

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