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Risk Management in Solitary Agricultural Work: New Technologies for Handling Emergency and Falls from Great Heights (SHADE)

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Abstract

Solitary work and agricultural activities are the scenarios of a large number of severe injuries and deaths, also because first aid may be difficult to achieve in isolated locations. This work proposes a technology available on smartphones that allows triggering an emergency call when a fall from height or an unconsciousness state is detected. The results of several tests, which include different detection algorithms and scenarios, are reported in this work. Tests performed with the aid of a dummy have allowed developing a reliable algorithm for the detection of dangerous situations. This system is available as an Android application.

Keywords: fall, safety, agriculture, app

1 Introduction

Solitary work happens when an operator works without the help or the direct contact with other people. Solitary work is not forbidden, but such occurrence requires particular regulations, especially when it happens during the night [1]. Therefore this kind of situation must be deeply investigated, considering the specific risks involved in working in solitude.

A major criticality is represented by the eventual distance from first-aid facilities, as well as the inaccessibility of the working area, and the frequency of access to the area, which should be evaluated along the whole working time [2]. The activities involved in agricultural work in non anthropized areas can be classified according to Table 1:

Work/task	Activity	Isolation level
Tractor operator/farmer [3]	Operation of agricultural vehicles (ploughing, towing of tools)	Total or partial
Forest ranger	Forest patrolling, tree cutting, monitoring of wild animals, forestall census	Partial (small groups)
Lumberjack	Tree cutting in forest, use of chainsaws	Partial
Alpine guide/Alpinist	Trekking guide in forest or mountain areas, generally hiking or riding horses/cars	Low isolation

Breeder [4]	Handling of large mammals: cleaning of hoofs, artificial insemination, milking, marking	Total
Hunters, hikers	Collecting of mushrooms, hiking in wild areas (mountains or forests)	Partial

Table 1: classification of solitary activities in isolated areas

Injuries caused by falls from height depend on two main causes: the impact between the human body and the stopping surface, and the sudden deceleration to which the body is exposed; both are related to the stiffness of the impact surface and to the amount of kinetic energy collected by the body during the fall. According to the available literature related to forensic pathology and to the analysis of accidents, deaths caused by fall from height are either voluntary, as in case of suicide [5] or accidental. Both are characterized by the following injuries:

1) External lesions are frequently of lesser magnitude if compared to internal ones, and they are mostly lacerated and bruised wounds caused by direct impact or by the exposure of bones or abrasions caused by the friction with walls during the fall [6]
2) The most frequent bone lesions are comminuted fractures of the skull, ring fractures of cranial basis, bilateral fractures of the heels, fractures of the femoral neck, and of the pelvis. Sometimes bone fractures are caused by violent muscular contractions with the detachment of fragments from the insertions [7]
3) The most common internal lesions due to deceleration consist in the detachment of the hearth from the vascular peduncle, the rupture of the aortic arch, and lacerations of liver, spleen and kidneys. [8] [10]

The target of this work is the development of a device capable of detecting emergency situations for workers in solitude, such as falls, unconsciousness, with also the capability to trigger automatically an emergency call. In order to spread as much as possible the accessibility of such technology, the system is available as an Android application. The main target for this application is constituted by professional workers, but it can also be used by hikers and people who enjoy the wilderness during their leisure time.

2 Materials and methods

The development process can be split into 5 phases:

1) Development of a database of lethal injuries due to falls
2) Contextualization of the accident scenarios
3) Choice of the testing methods
4) Development of the application
5) Prototyping and dynamic testing

The alarm situation happens according to the following rule:

$$Alarm = (a_1 1\ (FP) \vee a_1 2\ (FT) \vee a_1 3\ (FA) \vee a_1 4\ (FK))$$

a1(FP): this alarm situation refers to the posture of the operator. Thanks to the signal read by the inclinometer, the algorithm can detect if the inclination of the body (therefore the pitch angle of the phone) with reference to the ground is smaller than 45° for a sufficient amount of time
a2(FT): this alarm situation is triggered by the absence of motion by the operator: if the operator is motionless for a sufficient long amount of time, or at the end of the shift
a3(FA): this alarm is triggered in the presence of a fall from a great height
a4(FK): this feature allows to disable manually an alarm that is detected by one of the situations defined above, in order to filter possible false alarm or minor danger situations. If no alarm inhibition is given by the operator within a given amount of time, an emergency call is triggered automatically.

Therefore if one of the emergency situations a1, a2, a3 and a4 is encountered and the procedure is not disabled by the user, an emergency call is triggered. In this case SMS messages are sent to a pre-defined list of emergency contacts, listing the name, the location and the occupation of the operator.

The algorithm used to detect the alarm a1 (FP) can be described by the following pseudo-code:

```
start
#warning == 0
while (trigger_alarm = 0)
    read 1 pitch sample and add it to the buffer
    compute mean value of pitch β and the variance σβ over the last
20 samples
if σβ < 10 &&  -135 < β < -45
    play warning sound
    #warning ++
else
    #warning == 0;
end
if #warning > 49
    trigger_alarm == 1
end
end
```

The sampling rate for the inclinometer is set to 1.67 Hz, so that algorithm #1 is repeated every 0.6 s. The mean value of the pitch angle (measured in degrees) is evaluated on a sequence of the 20 most recent values sampled during the execution of algorithm, thus the data acquired in the last 12 seconds. The warning sound is played every time in which the operator stands still in a non-vertical posture, and in this occasion the counter of the warning is increased by one. If 50 consecutive warnings happen, i.e. after 30 seconds, an alarm is triggered. This procedure has been developed in order to inform the user that a suspect posture and steadiness has been detected. The user can disable the first level warning simply by moving: in this case the next computed values of mean pitch angle and/or the variance of the inclination will be over the threshold, and therefore the warning sound will not be played and the warning counter #warning will be reset. The threshold on the value of the variance of pitch angle σ_β is set to this value, in order to discriminate the result of voluntary motion from the involuntary motion, such as the one resulting from breathing.

The fall detection algorithm a3 (FA) is based on the simultaneous reading of data from accelerometer and inclinometer sensors. The sampling frequency is set to 20 Hz, therefore each sample is read at 50 ms interval. It should be highlighted that the sampling on an Android device is not constant, since the Android operative system does not allow to performing deterministic operation. The 50 ms interval between the samples acquisition is performed trough a Timer Task. This value has been chosen as a tradeoff between the accuracy of the procedure, which would require a fast acquisition, and the computing capabilities of the device on which the program is executed. The chosen setting showed to perform accurately also on low-end Android devices with a 1 GHz clock speed.

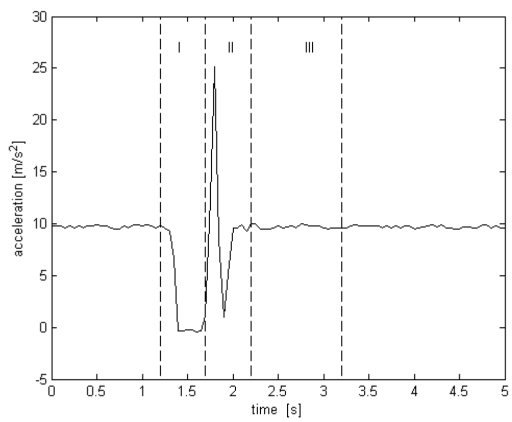

Figure 1: typical acceleration profile during a fall form 1 m

The procedure to detecting falls is based on the direct estimation of the values of total body acceleration, over a sequence of 40 samples, thus embracing a 2 seconds time window. Each time a new acceleration sample is available, the computation is repeated, so that the 40 samples window "slides" forward in time. The 40 samples window is divided into three parts, as shown in figure 3. A typical acceleration profile in case of fall can be divided in three parts: I) free fall, II) collision, III) steadiness. During a free fall the absolute value of acceleration quickly decrease to zero, since the raw measurement of acceleration on an Android device is performed by subtracting the gravity acceleration. Therefore the first 10 samples of the acceleration profiles are scanned to search how many samples are below the 3 m/s^2 threshold. If at least 3 samples are detected in this range, the first condition is met. The duration of the first part of the window is equal to 10 samples.

The second condition requires for at least one of the samples in the second part of the window to be over the 15 m/s^2 threshold. Again, the duration of the second part of the window is equal to 10 samples (i.e. 500 ms). The third condition is set on the 20 most recent values of acceleration and inclination. If the variance of the acceleration is lower than 3 and the mean value of the pitch is within the [-135, -45] deg. range, the third condition is met. The alarm is triggered if all the four conditions are met on a single sequence of 40 samples. In this case, a repeating warning sound is emitted and the actual help request is sent only if the user does not reset the procedure.

Simpler algorithms, i.e. the one based on the peak value of accelerations [10, 11], have been tested and discarded since they proved to trigger a large number of false positive warnings. In particular the conditions over the third windows have been introduced to eliminate the false positive cases that might arise during a running activity. During running gait the body mass is subject to alternative high impulsive acceleration and free “floating” phases, which might be mistaken as falls if the presence of a subsequent stance phase is not checked.

3 Results and discussions

The experimental tests were provided in order to emulate several typologies of falls. The results of the tests have been recorded by taking into account the following measurements:

- height of fall; (either forward, backwards or lateral)
- positioning of the sensing device; (top pocket or trouser pocket of the dummy, fig. 2)
- positive detection by the algorithm
- value of peak acceleration measured by the device

Figure 2: the dummy used for the experimental tests

A1t1p1	no		No		ok	21.67	no		no		ok	33.64	No	
A2t1p1	ok	26.72	No		ok	23.37	ok	24.82	ok	28.03	ok	16.67	Ok	28.36
A3t1p1	no		No		ok	33.47	ok	29.31	ok	29.37	ok	25.49	ok	25.36
A1t2p1	no		No		no		ok	31.14	no		ok	13.94	No	
A2t2p1	no		No		ok	20.44	no		no		no		No	
A3t2p1	no		No		no		no		no		ok	27.54	No	
A1t1p2	ok	17.05	Ok	16.24	ok	28.69	ok	17.89	no		no		No	
A2t1p2	ok	31.61	Ok	20.30	no		ok	25.04	no		ok	30.36	No	
A3t1p2	ok	33.99	Ok	33.97	no		ok	32.62	ok	21.52	No		Ok	31.78
A1t2p2	ok	29.14	No		no		no		ok	23.34	No		No	
A2t2p2	ok	32.78	No		ok	27.88	ok	34.02	no		No		Ok	16.52
A3t2p2	no		Ok	22.37	ok	22.85	ok	28.22	no		No		No	
A1t1p3	no		Ok	33.00	no		ok	19.38	no		No		No	
A2t1p3	no		No		no		ok	26.73	no		No		No	
A3t1p3	ok	34.02	Ok	24.21	no		ok	33.99	no		Ok	32.08	No	
A1t2p3	no		No		ok	27.79	no		no		No		No	
A2t2p3	no		No		no		ok	20.09	ok	32.92	Ok	18.46	No	
A3t2p3	no		Ok	33.79	ok	18.42	no		no		Ok	33.99	Ok	23.07

Figure 3 an extract from the database of experimental tests

An extract of the data collected during the experimental tests is shown in figure 3. The first column reports the code name of each test, which summarizes the testing condition, while the correct alarm detection is indicated in column 2.

During the development of the system several algorithms have been tested. The last one, which proved to achieve the best results, fulfills these goals:

- minimal sensitivity to sensor positioning: the algorithms can detect the fall for every height up to the maximum height tested, which has been limited to 8 m in order to avoid damage to the smartphone device
- minimization of the false positive detections: the algorithm is now insensitive to the solicitations induced by a running gait or a small jump. This goal has been achieved with a careful tuning of the parameters of the fall detection and lack of motion detection algorithms
- availability of an easy to use graphical interface that allows to trigger also manually the alarm procedure
- record of georeference data using also the last available location in case of unavailability of GPS signal

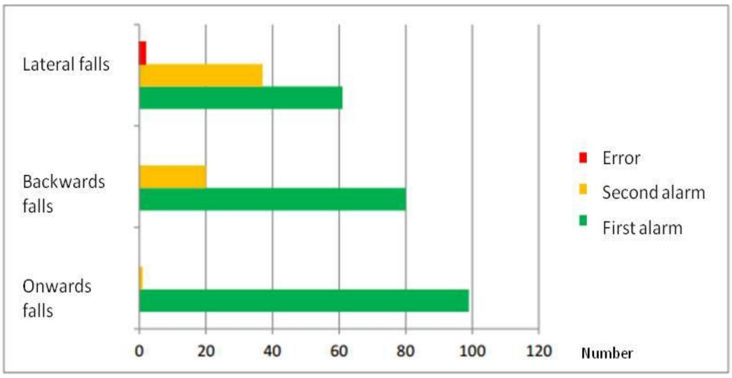

Figure 4: Results of experimental tests: detection of falls

Figure 4 reports the cumulative results of extensive experimental trials. The three groups of results show the number of positive and negative detection of emergency conditions, highlighting the results for sideways falls, backward falls and frontal falls. In only 2 cases among 300 trials, the alarm has not been triggered by the algorithms. These 2 cases can be explained by an imperfect execution of the test, which has required the use of excessive padding for the safety of the smartphone. Anyway a further analysis constituted by 150 additional tests concerning lateral falls has not shown any fault in the detection algorithm. It can be also seen that the fall detection algorithm is very effective for forward falls, while it is less efficient when backwards or lateral falls are encountered. On the other hand, the detection of lack of motion conditions can compensate for this lack, therefore leading to a very good performance of the proposed approach.
Further tests have been performed also on the field, including:

- falls from a tractor
- falls from silos stairs (biological risk)
- falls form chemicals storage areas (chemical risk)
- falls form high-stem plants
- falls form atex zones (risk of explosion)

4 Conclusion

This work is structured with a multi-disciplinary approach by joining aspects of software engineering together with forensic pathology and agricultural safety. Extensive tests, which involved more than 1000 trials, have highlighted the effectiveness of the system. The fall detection algorithms have proved to be less efficient for the collection of data concerning backwards falls, but this lack can be balanced out by the accuracy of data concerning the subsequent unconsciousness detection. Generally, also falls from relative small heights can be detected: this feature is important since this kind of occurrence can sometimes lead to lethal accidents. A major advantage of the proposed approach is its low cost: unlike commercially available systems, it does not require to pay a monthly fee. For this reason the proposed system is also available for hikers and occasional workers in isolated scenarios. [13],[18].
Future development of this work will include also specific solutions for elderliness, for people with degenerative diseases and for people that live in areas with a limited access to emergency services.

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