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AUTOMATING DATA EXTRACTION FROM GPS FILES AND SOUND PRESSURE LEVEL SENSORS WITH APPLICATION IN CABLE YARDING TIME AND MOTION STUDIES

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Abstract: *Finding ways to automate data processing activities represents a current challenge in most of the activity fields with obvious benefits that can be seen in the improvement of time management. In this study, we have developed a procedure able to extract time elements from GPS collected data with application in time and motion studies for cable yarding operations. Coupling GPS and sound pressure level sensors may prove to be very helpful in automating the procedures specific to time and motion studies implemented for cable yarding operations. For a given set of thresholds defined by the user in a computational algorithm, our results showed a ±2% agreement when comparing the moving and stopped states of the carriage as extracted from GPS files and sound pressure level sensors.*

Key words: *automation, sensors, GPS, computer programming, time and motion study, cable yarding.*

1. Introduction

An efficient implementation of timber harvesting operations relies to a great extent on knowledge about the technical, economic and environmental performance of timber harvesting systems. As a fact, such knowledge helped and triggered innovation in the harvesting equipment industry as well as the development of reliable and performant harvesting systems. Based on knowledge about technical limitations, environmental impact, ergonomics, economics and productive behaviour one can choose the best equipment or adapt the existing one to given operational environments [18].

At the same time, knowledge on the performance of timber harvesting systems and equipment is crucial in designing and developing effective forest product systems, with effectiveness spanning activities and processes located upstream and downstream the timber harvesting operations. It is known that data describing the performance of forest equipment can be used as models to build decision support tools and systems [12] or to

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optimize and control costing systems larger than those framed exclusively around the timber harvesting [11], [14]. Performance of timber harvesting systems is evaluated by implementing forest production studies that are seen as being crucial in maintaining the competitive edge of forest industries [15]. Typically, such studies focus on the productive and environmental performance [1] of harvesting systems but they can be implemented also to evaluate the ergonomic conditions of forestry work. For instance, in cable yarding operations, the implementation of such studies emphasized the benefits and drawbacks of changing the rigging and choker setting technology [19], [20]. In particular, modelling studies are useful to test the behaviour of a given harvesting system or equipment relative to its operational environment [24] while comparative studies help researchers to differentiate and choose the best alternative from a given set of options [1].

Time and motion studies are usually implemented to evaluate the productivity and time consumption for given harvesting equipment or systems. While being very useful in the past and constituting the backbone of forest production studies, traditional approaches (*i.e.* data collection on paper sheets using stopwatches) are characterized by a series of limitations (*i.e.* intrusion of researchers in the workplace that can generate biased data due to the observer's effects, exposure to accidents for those persons collecting the data in the proximity of hazardous machines, difficult terrain and rigors of open sky work [1], less effective data processing alternatives, resource requirements etc.). Nevertheless, such approaches are still used to validate the effectiveness and to compare the results yielded by the use of modern methods and many researchers believe that they will still be used in the future [15]. At the same time, it is often required to have models developed from population level data in order to be able to take informed decisions on the best options to be used but it would also involve the use of substantial resources in terms of personnel, logistics, money and time [2].

By comparison, partially or fully automated approaches, that use the capabilities of GPS (Global Positioning System), GNSS (Global Navigation Satellite System) coupled with GIS (Geographic Information System) and other kind of sensor systems showed a promising potential in the production, logistics and operations fields. In particular, they can substitute partially or fully the researcher's presence in the field [2], [7] and, in given cases, they have also the potential to substitute to some extent the human intelligence. In the performance assessment, their use spans both, short rotation coppice applications [5], [8], [22], [23] and traditional forestry [10], [16], [17], [21].

Due to specific topography, timber harvesting in steep terrain predominates in many European countries including Romania. However, the limited trafficability as well as the increased slopes leave few options for such operational environments [18]. While skidders may be used in steep terrain, there are many concerns related to time management, productivity and environmental performance, especially when the extraction distances are particularly high [3], [4]. In addition, cost components may prohibit their use when the slope exceeds 40-45% [18]. By comparison, cable yarding represents a traditional option in such terrains [13]. Sledge yarders are able to operate on long extraction distances as some of the existing models are built to operate to up to 2000 m [18]. Typically, they enable transportation, hoisting, skidding, handling and energy transfer functions as described by [13]. Timber transport from the felling site to landing relies on a skyline [13] which is more or less linearly mounted and sustains the movement of a carriage [18]. Recent research emphasized the potential directions to be approached in what concerns the research, development and use of cable yarders. In particular, the use of mechatronics to increase the work efficiency and improve its ergonomics as well as the improvement of computerized methods related to cable yarding planning are seen as directions with promising potential in the future [6]. However, some of such research directions would require forest production studies to validate the effectiveness of the developed solutions. At the same time, when conduction time and motion studies, researchers are likely to face steep terrains and hazards related to work near tensioned steel ropes. In addition, due to the specific setup of sledge yarders it is often required the presence of 2-3 researchers in the field that should be equipped with communication devices in order to be able to observe adequately the operations. Such issues triggered the development of new methods for data collection in cable-yarding time and motion studies. In particular, GPS and GNSS studies showed a lot of potential in collecting data and estimating the time consumption in cable-yarding operations [10], [17]. However, data extraction from GPS files may be challenging due to the large amount of information contained within.

The aim of this study was to develop an automated procedure for data extraction from GPS collected files with application in time and motion studies for cable-yarding equipment. In particular, the objectives were set to (i) finding free tools for data extraction from GPS collected files and to (ii) building an algorithm able to separate time consumption on specific functions by implementing a set of user-defined thresholds and tolerances.

2. Materials and Methods

2.1. Study Location

A filed study was carried out in a forest stand located near Zărneşti, Braşov County, Romania (Figure 1). Cable yarding operations were carried out in the study area by the means of a Wyssen sledge yarder. Felling area was located at (N) 45° 35.055’ (E) 25° 11.646’ at about 900 m above the sea level. The cable yarder was rigged for downhill yarding with the sledge mounted in the upper side. In the described configuration, cable yarder was operated by a 4-men team composed from 2 choker setters, one operator of the yarder and one man that worked to load detachment at the landing area.

2.2. Data Collection

A Garmin ® 60 stc GPS unit was placed on the carriage in a position that excluded as much as possible the obstruction of GPS signal, and it was setup to collect data at a 5 second rate.

Sound pressure level sensors (Extech ® VB300) were also installed on the carriage and near the engine of the yarder to continuously collect data. The two sensors were synchronized using time as a parameter and were started at the same time with the GPS unit. The sensors were setup to collect data at a time rate of one second. This approach was used to get comparative data to be used in the evaluation of carriage movement as derived from GPS data.

2.3. Data Processing and Algorithm Development

Data collected by the GPS device was

downloaded into a personal computer as a GPS exchange format (.gpx). Then the file was uploaded into BaseCamp ® which is a free software application developed by Garmin ®. It allows for data visualisation and editing as well as for the extraction of parameters needed in different kind of analyses using external software. In particular, the collected points may be copied along with their location and parameters of movement dynamics to be used in external software such as MS Excel ® that enables programming under Visual Basic for Applications ®. Leg parameters such as the leg index (integer) - LI, leg elevation (string) - LE, leg distance (string) - LD, leg speed (string) - LS, leg course (string) - LC and leg time (date) - LT were copied into a MS Excel ® sheet and served as an initial database. Then, we used simple MS Excel ® functions to extract and convert the string data into numbers that were copied into another sheet. The sound pressure levels (dB(A)) recorded by sensors on the carriage (CSPL) and engine (ESPL) were converted into new data series by extracting each fifth recorded value from the original data strings. Prior to that we used the VB300's ® dedicated software for downloading the data and converting it into MS Excel ® files. These new data strings were synchronized with the GPS data into a common MS Excel ® sheet. In the same sheet, we implemented a recalculation procedure for LD and LS variables, that allowed to obtain more precise data (two decimals), as well as a calculation procedure that enabled the extraction of LT (5 seconds) and cumulated time (CT). The derived database served as an input for programming procedures.

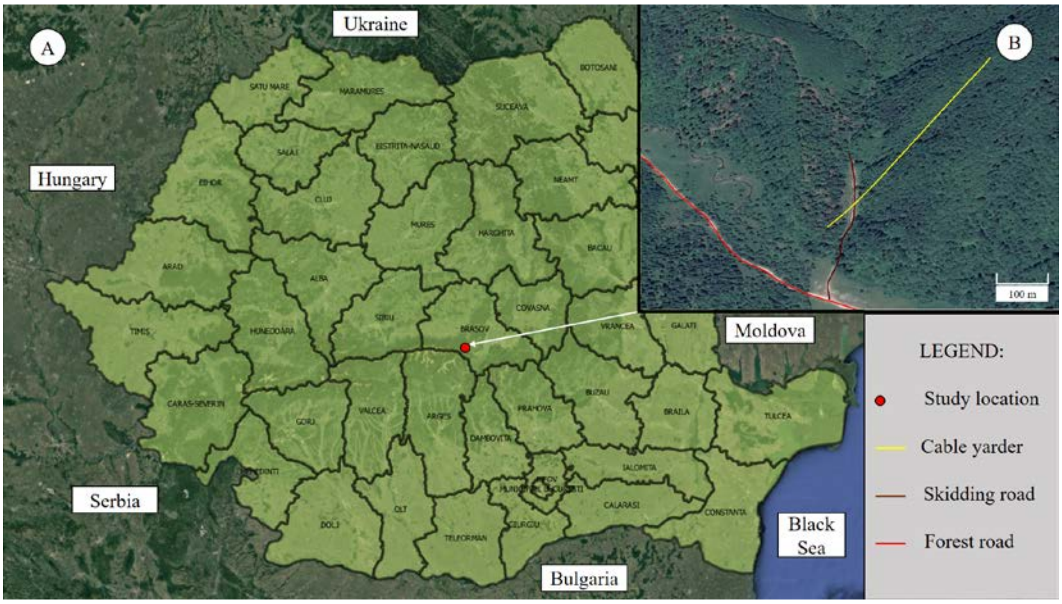

Fig. 1. *A map showing the study location. Prepared using Google ® Open Layers and Google Earth ® data*

Programming procedures were implemented to extract meaningful information from the GPS database. In particular, technical functions related to the carriage's kinematic behaviour were investigated. For this purpose, we used a three-state behaviour: moving uphill (MU), stopped (S) and moving downhill (MD). In theory and for the particular configuration and setup of the studied cable yarder, moving uphill is pretty much the same as the empty turn while moving downhill could be interpreted as the loaded turn. In practice however, not all of such movements correspond to the timber extraction functions. Also, the stopped state may span and overlap with time and work elements such as delays, lateral yarding including hooking-up the loads and landing. Nevertheless, the kinematic behaviour of carriage can provide useful information for gross time consumption and production [10]. On the other hand, parameters such as the movement speed, movement heading and elevation change as an effect of carriage movement may be significantly affected by GPS errors. Therefore, it is important to design programming algorithms that would enable the use of thresholds and tolerances, at least for the heading parameters.

In the programming phase, we approached the problem as described in Figure 3. We assumed that the carriage's kinematic state could be described by three parameters: leg course (LC), leg speed (LS) and leg elevation (LE). A first condition was set around the elevation state in the data string. The developed algorithm assumes three states: increments, decrements or no changes in the elevation of leg $i+1$ compared to leg i with the latter used to exit the programme and to write the state code, time and distance data in the allocated space as no movement (S). Then, the programme evaluates the movement speed based on a threshold defined by the user (ST). If the speed of a given leg exceeds the threshold then the algorithm steps to the next evaluation stage which takes into consideration user defined leg courses (headings) for uphill (LCu) and downhill (LCd) movement, as well as a user defined tolerance (DC). The user defined courses (headings) can be easily extracted from BaseCamp ®. This approach would be suitable also when dealing with multiple sets of data (*i.e.* several cable yarding setups located in different geographic locations that are likely to be characterized by general headings that are different).

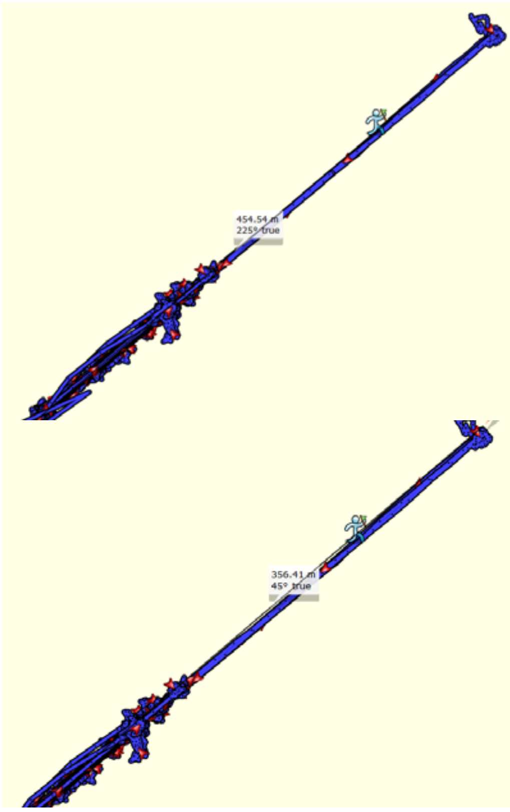

Fig. 2. *Extracting the Leg Course from BaseCamp ® using the Measure Tool: up - for downhill movement, down - for uphill movement.*

For the sound pressure levels, we used a single threshold value to differentiate between two carriage behaviours: movement and stopped. To this end, we used only the data extracted and processed from the sensor that was placed on the carriage.

The use of various forest equipment is characterized by various sound pressure levels [9]. Unfortunately, we couldn't find any references describing the sound pressure level emitted by carriages during operations. However, by plotting the data and comparing it with that provided by GPS (elevation and speed) it was more than likely that sound pressure levels greater than 80 dB (A) would correspond to the detection of effective carriage movement.

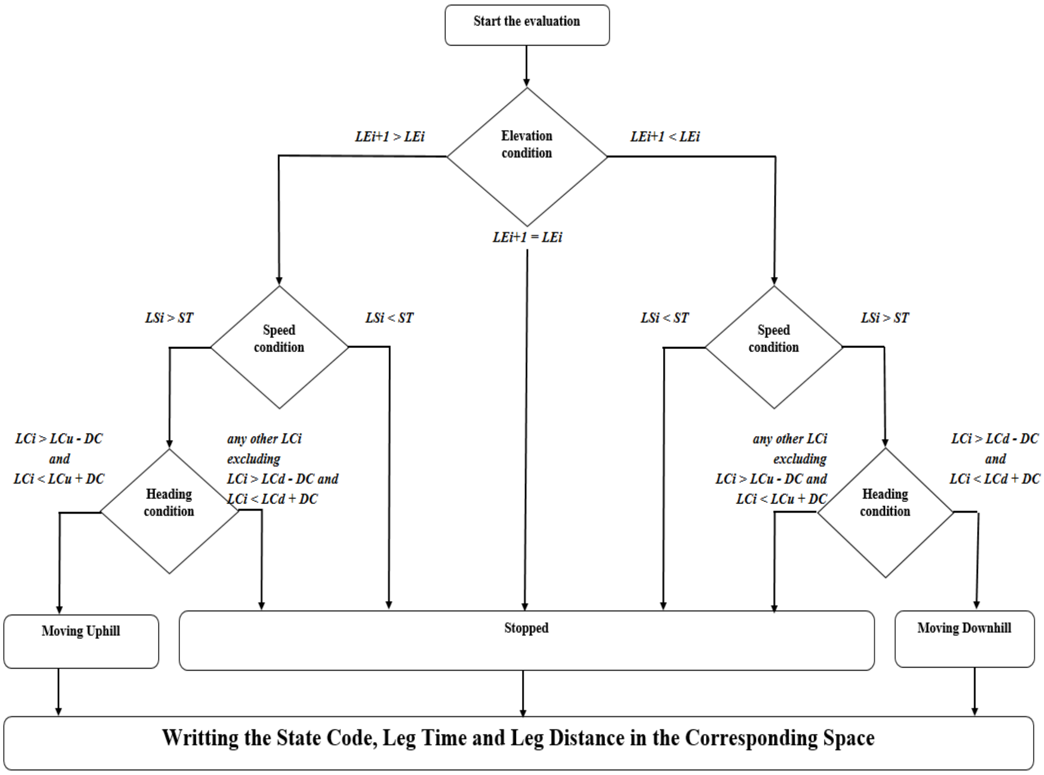

Fig. 3. *Logic of the algorithm developed in Visual Basic for Applications ® under MS Excel ® to extract time consumption elements from the GPS data files*

Finally, the GPS extracted data was summarized as graphics showing the kinematic behaviour of the carriage. To this end we have plotted the mentioned three states against the elevation and speed change.

The same approach was used to differentiate the carriage behaviour from sound pressure level data.

3. Results

An example of the used algorithm's outputs is graphically represented in Figure 4. To test and demonstrate the algorithm, we used a speed threshold of 0.25 m×s^{-1} as well as a tolerance of 15˚ for the leg courses as their values were described in Figure 2. As shown, there was a relatively good agreement between the data interpretation by the algorithm and the variations of elevation and speed corresponding to data extracted from the GPS file. Nevertheless, some of the parts could be misinterpreted as some parameters could match the threshold values by chance. Also, the presented data is a simulation as no comparative studies were conducted in the field to effectively identify the real behaviour of the carriage. Therefore, it relies on significant changes in elevation and speed as a reference data set while for intended applications data validation should follow the traditional approach that makes use of comparative studies.

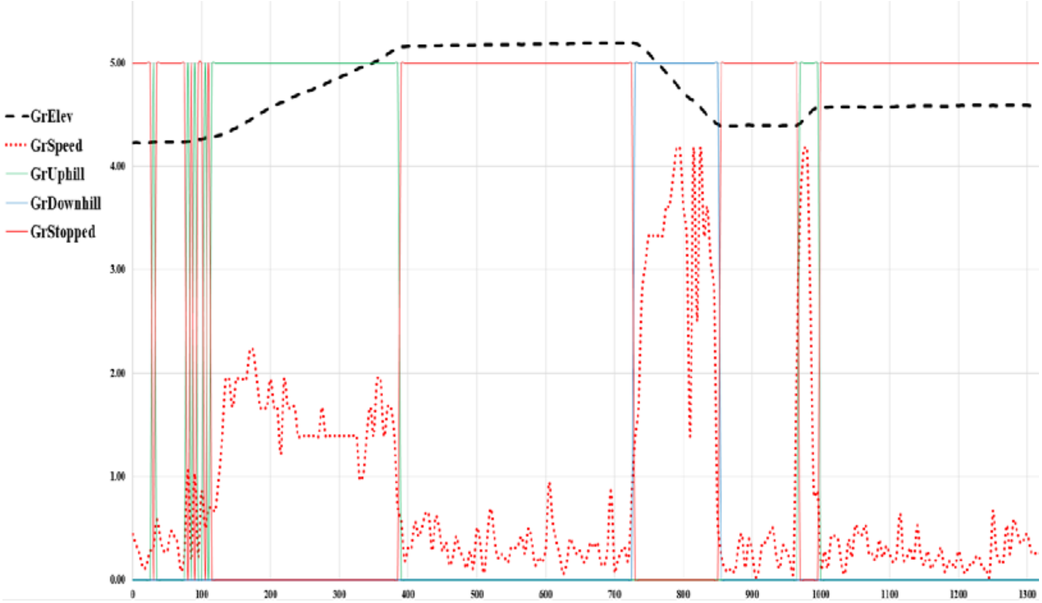

Fig. 4. *A snapshot showing the carriage behaviour as interpreted by the algorithm against the variations in elevation and speed from the GPS data. Legend: red - stopped, green - uphill movement, blue - downhill movement, dotted red - leg speed, dotted black - leg elevation (divided by a factor of 200)*

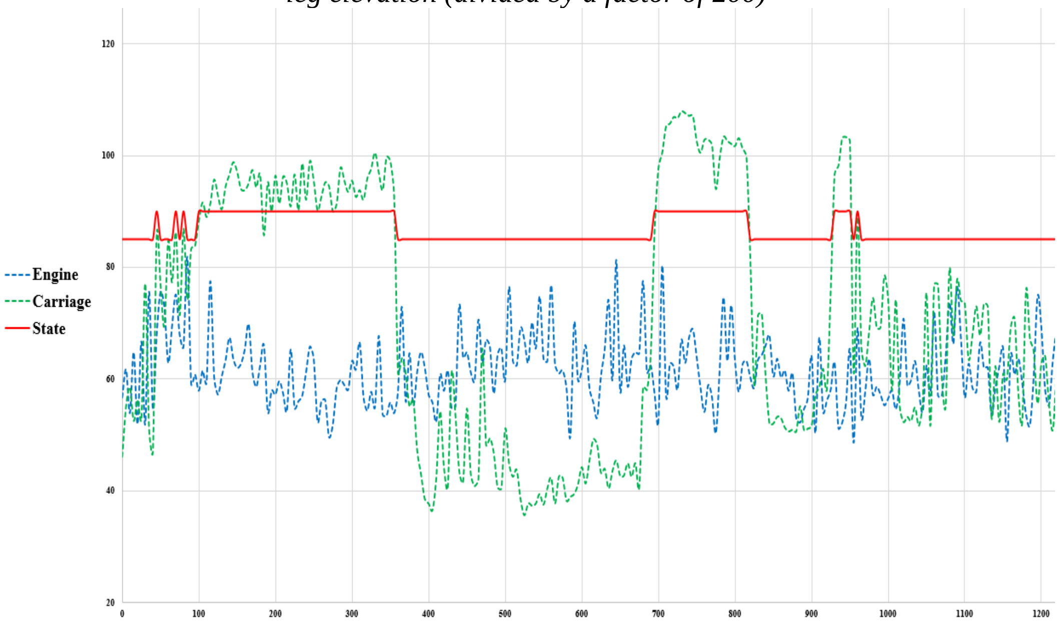

Fig. 5. *A snapshot showing the carriage behaviour as interpreted by the algorithm for sound pressure level differentiation.*

Legend: *red - carriage behaviour: high values - movement, low values - stopped, dotted blue - sound pressure level (dB (A)) against the time at the engine level, dotted green - sound pressure level (dB (A)) against the time at the carriage level*

However, it was not the scope of this paper to compare the data but to develop a procedure to automate data extraction and computation. It is typical for a carriage to advance at high speeds during the effective uphill and downhill movement [10], [17] but when changes occur in the carriage state, lower movement speeds can enter in the data pools depending on the sampling rate of GPS data. Typically, speed reduction occurs when passing over the shoes, before stopping to the choker setting area and when approaching the landing site to detach the load. To this end, we would recommend a sampling rate equal to the highest capabilities of GPS devices.

Elevation change, as shown in Figure 4, was typical to the data collected and processed in this study. However, cable yarders may be used to extract the timber uphill as well as in operations deployed in flat terrain [18]. Assuming high accuracies of the devices used to collect the data, the developed algorithm could still be implemented. Otherwise, the elevation condition should be excluded and the algorithm should rely only on the use of speed and heading thresholds and tolerances to extract the data.

Figure 5 shows a partition from the carriage behaviour (stopped *vs*. running) data as it was extracted from the sound pressure level sensors. Compared to Figure 4, it can be observed that the effective movements were characterized by sound pressure levels higher than 85 dB (A), a threshold that has been used to differentiate the two states in this study. While it is difficult to differentiate between the uphill and downhill movement, for gravity cable yarding setups, the latter may be carried out at higher speeds [10] compared to uphill movements. This was also the case of our visual observations in the field. At the same time, higher speeds may lead to higher sound pressure levels and could help differentiate the carriage behaviour using two thresholds. However, such an attempt would need more research.

The data used in this study covered about 11 hours of observation (39090 seconds). We have calculated the agreement of the GPS extracted data relative to the sound pressure level data for two kinematic behaviours (moving and stopped) and we found disagreements less than ±2% between the two data pools.

4. Conclusions

In this study, we developed and tested an algorithm able to extract the time consumption from GPS and sound pressure sensors collected data, as being specific to given cable yarding functions. One benefit of our approach resides in the automation of data processing that has the potential to improve the time management in such activities as a full data processing, including the operations carried out in BaseCamp ®, for a given set of thresholds defined by the user takes less than ten minutes. However, to be able to build time consumption models, additional organization of data would be required.

Sound pressure level sensors may be also used to extract meaningful information as shown in this study and they can be coupled with GPS data to help differentiate between specific cable yarding functions.

The thresholds used to differentiate the kinematic behaviour of the carriage were only simulations based on the available data. However, we found a good agreement of data interpretation by the algorithm for the two data sets: GPS *vs*. sound pressure level.

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