ABSTRACT

We present a tool for measuring the equivalent width (EW) in high-resolution spectra. The Tool for Automatic Measurement of Equivalent width (TAME) provides the EWs of spectral lines by profile fitting in an automatic or interactive mode, which can yield a more precise result through the adjustment of the local continuum and fitting parameters. The automatic EW results of TAME have been verified by comparing them with the manual EW measurements by the IRAF splot task using the high-resolution spectrum of the Sun and measuring EWs in the synthetic spectra with different spectral resolutions and signal-to-noise (S/N) ratios. The EWs measured by TAME agree well with the manually measured values, with a dispersion of less than 2 mÅ. By comparing the input EWs for synthetic spectra and EWs measured by TAME, we conclude that it is reliable for measuring the EWs in a spectrum with a spectral resolution of $R \gtrsim 20000$ and find that the errors in EWs are less than 1 mÅ for an S/N ratio $\gtrsim 100$.

Key words: methods: data analysis – techniques: spectroscopic – stars: fundamental parameters.

1 INTRODUCTION

The measurement of equivalent width (EW) for spectral absorption lines is essential in a spectral analysis, particularly for determining the atmospheric parameters and chemical abundances of stars. In the study of stellar spectroscopy, it is critical to determine the atmospheric parameters of stars, such as effective temperature ($T_{\text{eff}}$), surface gravity (log g), metallicity ([Fe/H]) and micro-turbulence ($\xi$), because atmospheric parameters are fundamental to understand spectroscopic properties and construct the model atmosphere for an abundance analysis. For the atmospheric parameters, however, the most common method is to analyse the abundances that can be obtained from EW measurements of neutral and singly ionized lines. Additionally, the chemical abundances are also estimated by measuring the EWs of atomic lines (e.g. Bensby, Feltzing & Lundström 2003; Santos, Israelian & Mayor 2004; Bond et al. 2006; Gilli et al. 2006; Sousa et al. 2006; Kang, Lee & Kim 2011). The EW measurement, therefore, is undoubtedly the most important task in spectroscopic studies.

The EWs of spectral lines have generally been measured by using the splot task in the IRAF echelle package, which makes it possible to manually estimate the EW of each line. Although this method guarantees a high degree of accuracy for EW measurement, it requires a disciplined expert in the field of stellar spectroscopy and the result depends on the personal bias. For an abundance analysis, it is necessary to measure the EWs for many lines for each star, which is a tedious and time-consuming task. Therefore, a uniform and fast method for EW measurement is required in stellar abundance studies using a large number of high-resolution spectra.

Sousa et al. (2007) presented a new C++ code, called ARES (Automatic Routine for line Equivalent widths in stellar Spectra), which can automatically and simultaneously measure the EWs of spectral lines in stellar spectra. ARES provides quick measurement results for EWs, without manual operation, from high-resolution spectra. However, the ARES code focuses on the performance of the code and hence deprives a user of the interactive operation that can be used to control an environment for each line. Further, a FORTRAN code for EW measurement, called DAOSPEC, was recently presented by Stetson & Pancino (2008). In order to achieve more accurate measurement, DAOSPEC offers the enhanced interactive mode for detailed manipulative tasks, such as the adjustment of the local continuum and the deblending of nearby lines. Unfortunately, ARES and DAOSPEC were written in C++ and FORTRAN, respectively. Therefore, the installation of ARES and DAOSPEC depends on the platform operating system (OS), and it would be difficult and inconvenient to compile and run these codes coherently, because of the required libraries (e.g. CFITSIO, GSL, SUPERMONGO, IRAF).

2 http://heasarc.nasa.gov/fitsio/fitsio.html
3 http://www.gnu.org/s/gsl/
4 http://www.astro.princeton.edu/~rhl/sm/sm.html

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1 IRAF is the Image Reduction and Analysis Facility software. It is written and supported by the IRAF programming group at the National Optical Astronomy Observatories that is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
To avoid these practical difficulties, we have developed the Tool for Automatic Measurement of Equivalent width (TAME),\(^5\) which is written in Interactive Data Language (IDL)\(^6\) and uses a graphical user interface (GUI). TAME can be used with any platform OS on which IDL has been installed, and it contains various features that are required to adjust the environment of EW measurement such as the local continuum and radial velocity of a star. Its semi-automatic mode (hereafter, the interactive mode) offers more flexible measurement of the EW as similar to DAOSPEC. And its fully automatic mode (hereafter, the automatic mode) can simultaneously measure the EWs for a large set of lines. TAME produces a formatted text file containing the EW result which can be used directly in the abundance analysis code MOOG (Sneden 1973), in addition to a graphical output file with the fitting results of the local continuum and line profile.

In this work, we describe the procedure by which TAME measures the EWs of spectral lines and examine the results of EWs obtained by TAME. In Section 2, we introduce the user interface and input parameters of TAME. In Section 3, we explain the automatic processes used to measure the EW with TAME, such as determining the local continuum, searching for blended lines and fitting the lines with a Gaussian/Voigt profile. In Section 4, we present the comparison of the manual EW measurements obtained using IRAF and those obtained using TAME for the high-resolution spectra of the Sun, whose atmospheric parameters are well known. We also discuss the difference between the EW estimated by TAME and the input EW for a synthetic spectrum having different spectral resolutions and S/N ratios. In Section 5, we summarize the advantages of using TAME along with its performance results.

2 INTERFACE AND INPUT PARAMETERS

The inputs, outputs and user interface of TAME are shown in Fig. 1. Initially, TAME requires the spectrum data in text format and the line list file that contains the line information such as wavelength, element index (for the MOOG code; e.g. ‘26.0’ for Fe I), excitation potentials (eV) and oscillator strength (log gf). The other parameters for EW measurement are obtained from the formatted text file, which contains parameters such as spacing of wavelength (SPACING), SNR for determining local continuum (SNR), smoothing factor (SMOOTHER) and measurable minimum EW (MINEW).

In this work, we describe the procedure by which TAME measures the EWs of spectral lines and examine the results of EWs obtained by TAME. In Section 2, we introduce the user interface and input parameters of TAME. In Section 3, we explain the automatic processes used to measure the EW with TAME, such as determining the local continuum, searching for blended lines and fitting the lines with a Gaussian/Voigt profile. In Section 4, we present the comparison of the manual EW measurements obtained using IRAF and those obtained using TAME for the high-resolution spectra of the Sun, whose atmospheric parameters are well known. We also discuss the difference between the EW estimated by TAME and the input EW for a synthetic spectrum having different spectral resolutions and S/N ratios. In Section 5, we summarize the advantages of using TAME along with its performance results.

\(^5\) TAME can be downloaded from http://astro.snu.ac.kr/~wskang/tame/

\(^6\) The IDL is a cross-platform software, providing support for Microsoft Windows\(^7\), Mac OS X, Linux and Solaris (http://www.exelisvis.com).

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high-resolution spectrum. It presents the spectrum near the target line and information of nearby lines adopted from Vienna Atomic Line Database (VALD; Piskunov et al. 1995; Ryabchikova et al. 1997; Kupka et al. 1999, 2000). After verifying an automatic result, the user can decide whether the EW of the line is reliable. If the user prefers, he or she can correct the local continuum and adjust the parameters for fitting, such as fitting function (Gaussian/Voigt), smoothing factor and radial velocity. In the automatic mode, TAME can also calculate the EWs of all target lines simultaneously, based on the default options described in the formatted parameter file.

3 METHODS

TAME measures the EWs of spectral lines with the following steps.

1. Determine the local continuum near the target line.
2. Normalize the local spectrum with the local continuum.
3. Identify the lines near the target line in the normalized spectrum.
4. Fit the target line with the Gaussian/Voigt profile with de-blending, if required.
5. Estimate the EW, full width at half-maximum (FWHM) and the centre wavelength of the target line from fitting.

In this section, we describe the main processes of the TAME program in detail, such as determining the local continuum level, searching for the lines and fitting the target line with the sample synthetic spectrum, which has a resolving power of $R = 10000$ and an S/N ratio of 100. We chose the low spectral resolution as the inputs of synthetic spectra, in order to show that TAME works well in the case of low spectral resolution. Then, we briefly discuss the two types of output files generated by TAME and demonstrate how TAME works for actual spectra by using the examples of metal-rich and metal-poor stars.

3.1 Determining the local continuum

TAME determines the local continuum near the target line according to the following steps.

1. Find the fitting curve in the trimmed spectrum by using the SPACING parameter with a polynomial function (order = 2).
2. Cut off the points below (the curve) $\times \{1 - 2/(\text{SNR parameter})\}$.
3. Derive a new curve by polynomial fitting with the residual points after the cut-off.
4. Iterate steps 2 and 3 until no points remain that need to be cut off.

We verified the process employed to determine the local continuum by using a synthetic spectrum whose S/N ratio = 100, for different SNR parameter values of 200, 100 and 50 (Fig. 2). If the S/N ratio were 100 and the noise followed a normal distribution, the $\sigma_{\text{noise}}$ of the continuum in the normalized spectrum would be 0.01 ($\approx \sigma_{\text{noise}} = 1/\text{SNR}$). Therefore, we would obtain the final data points representing the local continuum after recursively cutting off the points below the $2\sigma_{\text{noise}}$ value$^7$ of the polynomial fitting curve. Factually, we cannot completely reproduce the original continuum of the spectra only from the observed data. It would only be possible to predict the practical local continuum by using the S/N ratio of the observed spectrum. When using the SNR parameter = 100 (Fig. 2b), we found that the final local continuum had good agreement with the original local continuum, which was supposed to be unity, within a deviation of around 0.3 per cent ($\sim 0.003$). The standard deviation of the residual points (black) after iterations was very close to 0.01 ($\approx \text{S/N ratio of the synthetic spectrum}$). In the other cases, in which the SNR parameter = 200 and 50 (Figs 2a and c), the final local continuum appeared to be more curved than that for SNR = 100. In Fig. 2(a), the local continuum is determined at 0.5 per cent higher than the original continuum, and moreover, the shape of the continuum is highly tilted around the target line. This large discrepancy near the boundary region was because a large number of points were excluded by the input parameter condition, SNR = 200. In contrast, as shown in Fig. 2(c), when a large number of points were included for continuum fitting, their continuum severely descended around the centre. The local continuum problem is one of the main causes of EW errors (Stetson & Pancino 2008). Moreover, the errors arising from

$^7$ If noise follows a normal distribution, after the iterations, points in the upper 50 per cent (all points above the fitting curve) and lower 47.7 per cent (the points between the fitting curve and its lower $2\sigma_{\text{noise}}$) will remain on the final local continuum.
the local continuum cannot be completely quantified or predicted even though they are known to exist. Hence, the best method is to visually determine the local continuum, by experts who are highly disciplined with the stellar spectrum. However, it would be inefficient and time consuming to visually examine the local continuum for hundreds of lines only by eyes.

Therefore, TAME enhances the process used to determine the local continuum by using the interactive mode. TAME initially suggests the local continuum near the line, which is automatically determined by the SNR parameter. This local continuum level, which is numerically estimated, can be finely tuned by the user’s interaction. By pressing the ‘u’ or ‘l’ key, the local continuum level can be shifted up or down proportional to one fifth of 1/(SNR parameter). Eccentric points, which are suspected to be produced by the contamination from cosmic rays or bad pixels, can be excluded manually by pressing the ‘d’ key for that point. When the ‘c’ key is pressed, TAME enters the custom mode, which makes it possible to add points anywhere the user wants. This adjustment is then directly applied to the fitting result, and hence, it can be quickly verified by the user without the requirement of further operations.

### 3.2 Identifying the lines

After determining the local continuum, TAME numerically identifies the absorption lines in the normalized spectrum. For detecting the centre of the line in an arbitrary spectrum, we adopted the method that uses numerical derivatives and has been suggested by Sousa et al. (2007). TAME identifies the line centre using the following steps.

1. Determine the region for searching for lines, which appears to include all blended lines with the target line.
2. Calculate the second and third derivatives of the normalized spectrum smoothed with the SMOOTHER parameter.
3. Find the transition points in the wavelength, where the third derivative changes from positive to negative near the local maximum of the second derivative.
4. Calculate the exact wavelength using the linear interpolation near the transition points.

The numerical derivatives become much more noisy than the original spectrum, because of the noise divergence in a numerical calculation. Fig. 3 shows how the noise in the spectrum diverges in the cases without or with smoothing. Even when the noise is extremely small in the normalized spectrum, it rapidly multiplies in each numerical derivative calculation. In the case of no smoothing (Fig. 3a), many more lines are identified due to the noisy derivatives, which are amplified in each step of the calculation. When the spectrum and derivatives were smoothed with three or five points\(^8\) (Figs 3b and c), TAME properly detected two of the correct absorption lines even though the two lines were blended with each other. The input wavelengths of these two lines in the synthetic spectrum were 4913.62 and 4913.98 Å, and TAME finally estimated the wavelengths of these lines at 4913.61 and 4913.99 Å with an error of only 0.01 Å.

### 3.3 Gaussian/Voigt fitting

After searching for absorption lines, TAME calculates the EW of the target line by fitting with a Gaussian/Voigt profile. Based on the wavelengths of detected lines through the previous processes, TAME finds the best fit of spectral lines by least-squares curve fitting with the mpfit IDL library (Markwardt 2009). TAME outputs the EW and FWHM of the spectral line as follows.

1. Generate the model functions of spectral lines based on the number of detected lines. For example, if two lines are detected and the user plans to use a Gaussian profile, TAME makes the model function including two Gaussian profiles:

   \[ F_{\text{model}} = 1 - \sum_{i=1}^{2} \text{Gaussian}(\text{wavelength}_i, \text{FWHM}_i, \text{EW}_i). \] (1)

2. Set the initial value and the range of each parameter such as wavelength and FWHM.
3. Find the best fit by starting with the initial value of each parameter.

Fig. 4 shows the fitting results of the synthetic spectrum for a Gaussian profile. As shown in Fig. 4, TAME estimates the centres of two lines at 4913.62 and 4913.98 Å by Gaussian profile fitting and obtains the EWs of those lines at 50.8 and 56.9 mÅ. Considering

\(^8\) We used a boxcar average for smoothing, \[ R_i = \frac{1}{w} \sum_{j=0}^{w} I_{i+j\cdot w/2}, \] \(w = \) smoothing width.
that the input EWs of these lines are 49.8 and 56.2 mÅ, the estimated EWs are in very good agreement with the input EWs, having differences within only 1 mÅ. We confirmed that despite the line deblending, TAME can estimate the accurate EWs in the synthetic spectrum with $R = 10\,000$ and S/N ratio = 100.

3.4 Outputs

After the completion of the EW measurement, TAME outputs a text file and a graphical post-script file. The text output file is written in the same format as the input file of the abfind driver of the MOOG code (Sneden 1973), in order that the user can instantly calculate the abundances of lines using the MOOG code. This text output also contains the line centre and FWHM of the fitting profile, and the radial velocity calculated by the difference between the rest-frame wavelength and the measured wavelength for each line. The representative radial velocity of the star can be derived by averaging the radial velocities of individual lines along with their standard deviation. Additionally, the FWHM of the line and the $\chi^2$ value from the fitting could be used for the diagnostics of lines. Each atomic spectral line has a specific FWHM for each wavelength, atomic mass and stellar effective temperature. Extremely broad or extremely narrow lines, relative to the others, can be expected to be affected by obscure lines or to not originate from the stellar atmosphere, and therefore, they can be neglected in the EW results. This is because the broad lines that are closely blended with each other cannot be deblended due to the limit of the spectral resolution.

The graphical output file shows the spectrum and fitting plots of the local continuum and the line profile for each line. Because TAME generates these plots in a post-script file, the user can easily open and print this graphical output. When performing the abundance analysis, the graphical output is very useful for checking whether the abundance of each line is well determined. The EWs of more than tens of lines are generally adopted for the chemical abundance of one element. If the abundance of a line is located far from the abundance distribution of the other lines of the same element, the graphical output can help with inspecting the spectrum around aberrant lines and their fitting plots.

3.5 Examples using the spectra of metal-rich and metal-poor stars

We examined the process of EW measurement performed by TAME with the actual spectra of HD 75732 ([Fe/H] = +0.35) as a metal-rich star and HD 155358 ([Fe/H] = −0.63) as a relatively metal-poor star. These spectra were obtained at Bohyunsan Optical Astronomy Observatory (BOAO) with the BOAO Echelle Spectrograph (BOES) (Kim et al. 2002, 2007) in 2008 and have the spectral resolution $R = 30\,000$ and an S/N ratio of ∼200 (Kang et al. 2011).

Fig. 5 shows the local continuum fitting results for the FeI line at 5250.22 Å for two sample stars. For the metal-rich star HD 75732, the central region of the local continuum appears to sink below about 2 per cent, relative to the side region. This is, as mentioned above, because of the undersampling of the points that are used to determine the local continuum in this spectral region. It is difficult to manage this bending local continuum in a crowded region with computational manipulation, because neglecting a very large number of points by a statistical method might produce an unstable fitting result. The best solution for metal-rich stars, such as HD 75732, is to confirm the fitting results visually and to correct them through manual interaction. Further, we observed that the local continuum of the metal-poor star HD 155358 was well determined.

Fig. 6 illustrates the fitting results with Gaussian and Voigt profiles. For the test, we plotted the fitting results of all the lines near the target line beyond the region that appeared to be blended with nearby lines. In normal cases, TAME automatically defines the blended region by comparing the line features with the local continuum level and performs fitting only with the points in that region. In the case of HD 75732, it can be seen that there are several lines that do not match the Gaussian profile. The line at 5249.08 Å seems to be blended with a weak line, which cannot be detected by the method that uses numerical derivatives. The EWs of two lines at 5250.22 and 5250.65 Å are more than 100 mÅ and, hence, show a better fitting result when a Voigt profile is used. In contrast, the fitting result of the metal-poor star HD 155358 shows a better $\chi^2$ and fitting result for a Gaussian profile, because the lines for this star are much weaker than those of metal-rich HD 75732.

As a result, it can be concluded that TAME appears to work acceptably for metal-poor stars, even in the automatic mode, and that
Figure 5. The determination of the local continuum for the two cases of a metal-rich and a metal-poor star, i.e. HD 75732 and HD 155358. The lower panels show the magnifying results around the continuum.

Figure 6. The line detection and fitting results of HD 75732 and HD 155358. The black dots represent the observed spectrum, and the grey vertical thick lines indicate the positions of detected lines. The grey dotted lines and grey solid lines denote the fitting profile for each line and for all the lines, respectively.

careful adjustments in the interactive mode might be required for metal-rich stars or for strong lines.

4 RESULTS

The EW result of TAME has been validated by comparing it with the EWs measured by the IRAF splot task and by applying TAME to various synthetic spectra. The EWs in the solar spectrum have been manually measured by the IRAF splot task and automatically estimated using TAME. Then, we observed whether TAME is appropriate for the abundance analysis by investigating not only the difference in the EWs but also the atmospheric parameters derived with these EWs. In order to evaluate the reliability for a variety of spectra, we examined the EWs measured by TAME for synthetic spectra having different spectral resolutions and S/N ratios.

4.1 Comparison with manual measurements

We estimated the solar EWs of atomic lines using TAME and the IRAF splot task. The high-resolution spectrum of the Sun has been obtained with BOES and has a spectral resolution of \( R = 30000 \) and S/N ratio \( \gtrsim 300 \).

Fig. 7 shows the result of comparing the EWs obtained using the IRAF splot task and those estimated by TAME. The average and standard deviation between two EW results are acceptable at \(-0.69\) and 1.76 mÅ, respectively. In the plots of the EW difference versus the wavelength and EW, it appears that the EW differences depend on the wavelength and have no dependence on the EW. At a short wavelength (\( \lesssim 5500 \) Å), as shown in Fig. 7(b), the difference in the EW measurement decreases to \(-5\) mÅ and becomes more scattered. This is largely owing to the local continuum determination in the crowded region, where TAME cannot avoid the undersampling of fitting points. The undersampling of valid points reduces...
Figure 7. The comparison between the EWs measured by the IRAF splot task and those obtained using TAME. The top panel shows the difference between the two measurements, and the middle and bottom panels show the trends in the EW differences along the wavelength and EW for each line.

Figure 8. The results of the fine analysis performed using the EWs of the Fe I and Fe II lines. The four plots on the left show the abundances obtained from the EWs measured by the IRAF splot task and the plots on the right show those obtained using the EWs measured by TAME. The dashed lines denote the linear fitting results.
Figure 9. The sample plots of the input EWs for the synthetic spectra and those measured by TAME. The plots show the results for three different kinds of synthetic spectra, which have (SNR, R) = (100, 20000), (50, 20000) and (100, 10000) in the case when the SMOOTHER parameter = 3. The plot in the middle represents the example of a low S/N ratio, and the plot on the right shows how the EW measurement changes when the spectral resolution decreases with respect to the plot on the left.

Figure 10. The detection ratio of lines and the difference between the input and measured EWs by TAME (for SMOOTHER = 3). The error bars in the lower plots represent the standard deviation of EW differences for each spectral resolution and each S/N ratio.

In order to investigate the variation in the EW measurement resulting from the properties of the spectrum, we calculated the detection rate of lines and the difference between input and measured EWs for each S/N ratio and each spectral resolution. As shown in Fig. 10, we found that the EW difference between the input and measured values converged rapidly to zero when the spectral resolution increased (especially, R ≳ 20000) and less sensitive to the noise in the spectrum. Similarly, as the EW difference increased, the detection rate also decreased with a decreasing spectral resolution. The average EW difference sharply decreased below −15 mA at a low resolution of R = 5000, and particularly, in the case of S/N ratio = 50, the EW difference reduced to −25 mA. This is because TAME is likely to deblend the target line into arbitrary several lines in the spectrum with low resolution. The depth of the absorption line becomes more shallow when a spectral resolution decreases, and hence, the noise patterns can be confused with a feature of the absorption line in numerical line identification. This also explains why the detection rate decreases at a low spectral resolution. However, excessive deblending by TAME can be reduced by using a large SMOOTHER parameter in most cases. From the data in Table 1, we could confirm that using a higher SMOOTHER parameter (= 5) causes the detection rate to become much higher and the average difference further stabilizes even for a low resolution of R = 5000.

From this assessment, we conclude that TAME is reliable for measuring EWs in the spectrum of a typical high-resolution echelle spectrograph, which has a spectral resolution of R ≳ 20000, and the rms result indicates that the error in EW measurement reduces to less than 1 mA for an S/N ratio ≳ 100.
Table 1. Line detection ratio and statistics of the difference between the input and measured EWs for different spectral resolution and S/N ratio values of synthetic spectra.

| Resolution | SNR | SMOOTHER = 3 | Detection (per cent) | Avg. (mÅ) | rms (mÅ) | SMOOTHER = 5 | Detection (per cent) | Avg. (mÅ) | rms (mÅ) |
|------------|-----|--------------|---------------------|-----------|----------|--------------|---------------------|-----------|----------|
| 5000       | 50  | 73.80        | −25.978             | 18.528    |          |              |                      |           |          |
| 5000       | 100 | 74.17        | −23.656             | 17.121    |          |              |                      |           |          |
| 5000       | 150 | 73.43        | −23.907             | 18.177    |          |              |                      |           |          |
| 5000       | 200 | 70.85        | −22.461             | 16.869    |          |              |                      |           |          |
| 5000       | 300 | 67.53        | −18.683             | 15.031    |          |              |                      |           |          |
| 10000      | 50  | 92.99        | −7.200              | 7.317     |          |              |                      |           |          |
| 10000      | 100 | 96.31        | −3.081              | 4.078     |          |              |                      |           |          |
| 10000      | 150 | 96.68        | −2.018              | 3.242     |          |              |                      |           |          |
| 10000      | 200 | 97.79        | −1.138              | 2.399     |          |              |                      |           |          |
| 10000      | 300 | 98.15        | −0.463              | 1.585     |          |              |                      |           |          |
| 20000      | 50  | 98.52        | −0.001              | 2.468     |          |              |                      |           |          |
| 20000      | 100 | 99.26        | 0.032               | 0.790     |          |              |                      |           |          |
| 20000      | 150 | 99.26        | −0.046              | 0.504     |          |              |                      |           |          |
| 20000      | 200 | 100.00       | 0.030               | 0.434     |          |              |                      |           |          |
| 20000      | 300 | 99.63        | 0.036               | 0.283     |          |              |                      |           |          |
| 50000      | 50  | 99.26        | 0.013               | 1.400     |          |              |                      |           |          |
| 50000      | 100 | 99.63        | 0.060               | 0.689     |          |              |                      |           |          |
| 50000      | 150 | 99.63        | 0.053               | 0.441     |          |              |                      |           |          |
| 50000      | 200 | 99.63        | 0.064               | 0.338     |          |              |                      |           |          |
| 50000      | 300 | 99.63        | 0.069               | 0.269     |          |              |                      |           |          |
| 100000     | 50  | 99.26        | 0.182               | 1.279     |          |              |                      |           |          |
| 100000     | 100 | 100.00       | 0.048               | 0.711     |          |              |                      |           |          |
| 100000     | 150 | 99.26        | 0.094               | 0.533     |          |              |                      |           |          |
| 100000     | 200 | 99.26        | 0.081               | 0.453     |          |              |                      |           |          |
| 100000     | 300 | 99.26        | 0.097               | 0.362     |          |              |                      |           |          |

5 SUMMARY

We have developed a new software tool for automatic EW measurement called TAME for measuring EWs in a high-resolution spectrum. It has the following features.

(i) TAME can automatically measure EWs for a large set of lines in a spectrum simultaneously.
(ii) TAME offers an interactive mode, in which a user can adjust the local continuum level precisely and change parameters such as SMOOTHER, radial velocity and type of fitting profile (Gaussian/Voigt).
(iii) TAME provides a text file including the EWs with a format suited for the MOOG code and a graphical post-script file for confirming the EW results when performing abundance analysis.

We verified TAME in two ways. By using the solar spectrum, we measured solar EWs by TAME and compared them with those obtained by the traditional method with the IRAF splot task. The EWs measured by TAME showed good agreement with the precise manual measurements made using IRAF, with a standard deviation of only 1.76 mÅ, and the atmospheric parameters of the Sun were determined to be Teff = 5791 K, log g = 4.54 dex, [Fe/H] = 0.03 dex and ξ = 0.81 km s−1 from the EW result of TAME.

In order to examine the effect of the S/N ratio and spectral resolution on EW measurement, we performed EW measurement for different synthetic spectra by using TAME in the fully automatic mode without any manual interactions. From the test results obtained for the synthetic spectra, we concluded that the EW measurements obtained by TAME are reliable for high-resolution spectra with R > 20,000 and found that the errors in EWs could be expected to be less than 1 mÅ for an S/N ratio ≥ 100.

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REFERENCES

Bensby T., Feltzing S., Lundström I., 2003, A&A, 410, 527
Bond I. C., Tinney C. G., Butler R. P., Jones H. R. A., Marcy G. W., Penny A. J., Carter B. D., 2006, MNRAS, 370, 163
Castelli F., Kurucz R. L., 2003, in Piskunov N., Weiss W. W., Gray D. F., eds, Proc. IAU Symp. 210, Modelling of Stellar Atmospheres. Astron. Soc. Pac., San Francisco, p. A20
Gilli G., Israeliian G., Ecuvillon A., Santos N. C., Mayor M., 2006, A&A, 449, 723
Kang W., Lee S.-G., Kim K.-M., 2011, ApJ, 736, 87
Kim K.-M. et al., 2002, J. Korean Astron. Soc., 35, 221
Kim K.-M. et al., 2007, PASP, 119, 1052
Kurucz R. L., 1993, CD-ROMs, ATLAS9 Stellar Atmospheres Programs and S/N ratio values of synthetic spectra.

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Markwardt C. B., 2009, in Bohlender D. A., Durand D., Dowler P., eds, ASP Conf. Ser. Vol. 411, Astronomical Data Analysis Software and Systems XVIII. Astron. Soc. Pac., San Francisco, p. 251
Piskunov N. E., Kupka F., Ryabchikova T. A., Weiss W. W., Jeffery C. S., 1995, A&AS, 112, 525
Ryabchikova T. A., Piskunov N. E., Kupka F., Weiss W. W., 1997, Balt. Astron., 6, 244
Santos N. C., Israeli G., Mayor M., 2004, A&A, 415, 1153
Snedden C., 1973, PhD thesis, Univ. Texas
Sousa S. G., Santos N. C., Israeli G., Mayor M., Monteiro M. J. P. F. G., 2006, A&A, 458, 873
Sousa S. G., Santos N. C., Israeli G., Mayor M., Monteiro M. J. P. F. G., 2007, A&A, 469, 783
Stetson P. B., Pancino E., 2008, PASP, 120, 1332

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