

Results and Discussion

Microscopic examination

In general, based on microscopic examination, the distribution of ink onto the paper substrate upon writing was found different where ten written samples using gel pens have shown more even and smoother ink distribution with visible ink diffusing into the paper substrate. Ink bleedings from gel pen inks were observed, as demonstrated in Figure 1(a). In comparison, the written ink using ballpoint pens was found to exhibit poorer and less smooth ink distribution with features of halo, Figure 1(b) and fine striations, Figure 1(c). Halo and fine striations had been absent in those handwritten samples produced by gel pen in this study.

During writing, ink is deposited onto the substrate and the solvents are subsequently evaporated leaving behind the coloured particles [20]. In this study, the paper used as the substrate was a porous surface, and it allows the diffusion of liquid ink into the paper. Therefore, a less viscous characteristic of ink reserved in a pen could potentially produce a more even appearance of trace on a paper upon writing as demonstrated by gel pen ink. On the other hand, a relatively thicker or paste-like consistency ballpoint pen ink could have contributed to less diffused writing features on the paper substrate making the inked-trace appear as being stained on the surface of the paper.

In our written ink samples using ballpoint pens, the formation of a halo as a small gap that discontinued smooth writing was observed in eight out of ten handwriting samples and it could be due to the inadequate ink flow from the pen reservoir [21]. This feature was found along with fine striations on the handwriting samples as a distinctive pattern [3]. Accumulation of dried ink might cause uneven distribution of ink on the rollerball of a ballpoint pen [21]. Note that in our case, the functionality of all pens was tested before writing. Observation of halos and gaps could be due to the restriction of the smooth flow of more viscous ink from the reservoir onto a substrate, leading to a tendency of ink to be retained on the surface of roller ball.

The mechanism of ink deposition has contributed to different morphological features on written samples produced by different types of pens. In general, the microscopic examination could suggest the types of pens of different ink type, in this case, ballpoint pen and gel pen inks. However, microscopy alone could not confidently help to discriminate traces written with two pens of very similar type, and therefore more detailed physical and chemical examinations are required.

Hyperspectral Imaging using Video Spectral Comparator-6000

Under UV light examination, all 20 samples revealed no luminescence characteristics. However, certain ink samples luminesced with the application of different barrier filters to the light sources, and the luminescence characteristics of written ink samples in this study were demonstrated in Table 2.

Based on VSC analysis, the ink samples could be categorised into three different luminescent categories, namely (i) inks that contained no luminescent component, (ii) inks that contained luminescent components and (iii) inks that luminesce at certain wavelength exposure [18]. Out of 20 samples, ten of them (i.e., 7 ballpoint pen inks and 3 gel pen inks) showed no luminescence regardless of the filter barriers. Based on the luminescence characteristic, both filters of respective wavelength values ranging from 400 – 535 nm and 485 – 610 nm did not show much difference in luminescence output, except in three samples (i.e., GP02, GP03 and GP04) that demonstrated bluish glows when applied with the latter. The filter of longer wavelength (i.e., 605-730 nm) provided only limited information, where only five samples (i.e., BP02, BP05, BP08, BP09 and BP10) luminesced in white and another three in blue (i.e., GP02, GP03 and GP04) against dark backgrounds. However, a combination of filters of varying wavelengths was found to be useful for ink discrimination. Based on the results, four different groups of ink characters could be established, firstly by 485 – 610 nm wavelength filter to determine the presence of luminescence characteristic as well as their respective colours, followed by the filter of longer wavelength (605- 730 nm) to differentiate the bluish