Zoosymposia 18: 160–178 (2020)
https://www.mapress.com/j/zs

ISSN 1178-9905 (print edition)
ZOOSYMPOSIA
ISSN 1178-9913 (online edition)

https://doi.org/10.11646/zoosymposia.18.1.20
http://zoobank.org/urn:lsid:zoobank.org:pub:ECA79671-B19C-4FC4-9273-ABC08168E7D0

New techniques for improving resolution and visual information on flight activity in Trichoptera

W. GEOFF McILLERON[1,5] & FERDINAND C. DE MOOR[2,3,4,6*]
[1]*103 St. Michael's Avenue, Nature's Valley, P O Box 266, The Crags 6602, South Africa*
[2]*Department of Freshwater Invertebrates, Makana Biodiversity Centre, Albany Museum, Grahamstown 6139, South Africa.*
[3]*Department of Zoology and Entomology, Rhodes University, Grahamstown 6139, South Africa.*
[4]*South African Institute for Aquatic Biodiversity (SAIAB) Grahamstown 6139, South Africa*
[5] *geoffmcilleron@gmail.com; https://orcid.org/0000-0002-7315-6482*
[6] *f.demoor@ru.ac.za; https://orcid.org/0000-0003-4624-7191*
[*] *Corresponding author: f.demoor@ru.ac.za*

Abstract

Earlier design and use of photographic rigs for recording insects in free flight, and the applications and shortcomings of those efforts are reviewed. Improvements included the following: Replacement of laser beams with infrared (IR) LED beam-emitters and IR phototransistor detectors; an array of nine intersection points to increase the possibility of capturing images; improved electronic circuitry to avoid multiple image capture; more energy-efficient and smaller UV light sources to attract insects; a more rigid aluminium frame to support the UV and IR LED transmitters and detectors; development of an ultra-high-speed flash system 5 µs, or faster, to produce even sharper images than those produced by the 25 µs standard speedlight flash units set at 1/128th power; and a transportable wooden box to house all the electronic components and mounts for cameras and speedlights. This paper describes the design features of the rig and its use in the field and illustrates and compares photographic results obtained using a variety of photographic techniques aimed at providing high quality, sharp, images of insects in free flight, continuous traces of the flight pattern of insects, strobe images, and combinations of these techniques. From these images reasonably accurate estimates of insect size, wing beat frequency, flight speed, and information on mechanics of flight can be obtained.

Key words: Trichoptera, ultra-high-speed LED flash, flight, photography technique

Introduction

At the 13th International Trichoptera Symposium in Poland in 2009, the current authors delivered a paper that described the basic techniques used to photograph insects in flight (McIlleron & de Moor 2011). A specially designed and constructed rig employed intersecting light beams to trigger high speed electronic flash units whenever a pair of beams was interrupted by an insect flying through them. In the original design of the rig, red lasers directed by mirrors were used as light beams. This system had significant disadvantages: the mounting of the lasers, mirrors, and light sensors demanded careful design and the precision system was set-up in the workshop and further adjusted in the field. The early rigs were not robust and prone to alignment problems. The high intensity laser beams also disfigured some of the images by superimposing bands of red laser light on the insect, a phenomenon that was also noted by Cognisys (2019). Close inspection of the images indicated that, at the flash durations of 25 µs (about 1:40,000th of a second) used, the high-speed movement of insects, especially those relating to the wing tips of smaller insects, were not as sharp ('frozen') as needed to meet modern photographic standards. Recent work in which specialised high-speed LED's instead of commercial electronic flash units were used, demonstrated that a noticeable improvement in acuity is obtained. In addition to individual images of insects in flight, the use of the rig has been extended to produce images of the flight traces of insects after they fly through the focus plane of the camera. The traces can be featured as stand-alone images of the flight trace or synchronised with flash to combine sharp images of the insect superimposed

 Submitted: 7 Nov. 2019; Accepted by Pongsak Laudee: 26 Feb. 2020; published: 12 Jun. 2020

upon its flight trace. These photographs are often visually appealing and provide insightful information on the mechanics of flight of the insect. Initially, flight traces were produced using a bright incandescent light which imposed a heavy drain on the batteries and was difficult to synchronise manually with the insect's flight through the beams. This technique also caused considerable degradation of images because the incandescent light remained on during the full duration of the camera exposure, causing "fogging" or flare of the images.

Publications on photography of insects in flight have discussed straight-forward techniques using manual pre-focus or the autofocus capability of the camera to capture sharp images as an insect approaches or leaves a specific landing spot such as a flower (Fox 2013). For the autofocus system to perform accurately, daylight or an alternative strong source of light is needed as well as a specialised system to assist the photographer to achieve an exact point at which to aim the camera. Such techniques are unsuitable for night-flying insects such as most Trichoptera species and moths (Lepidoptera).

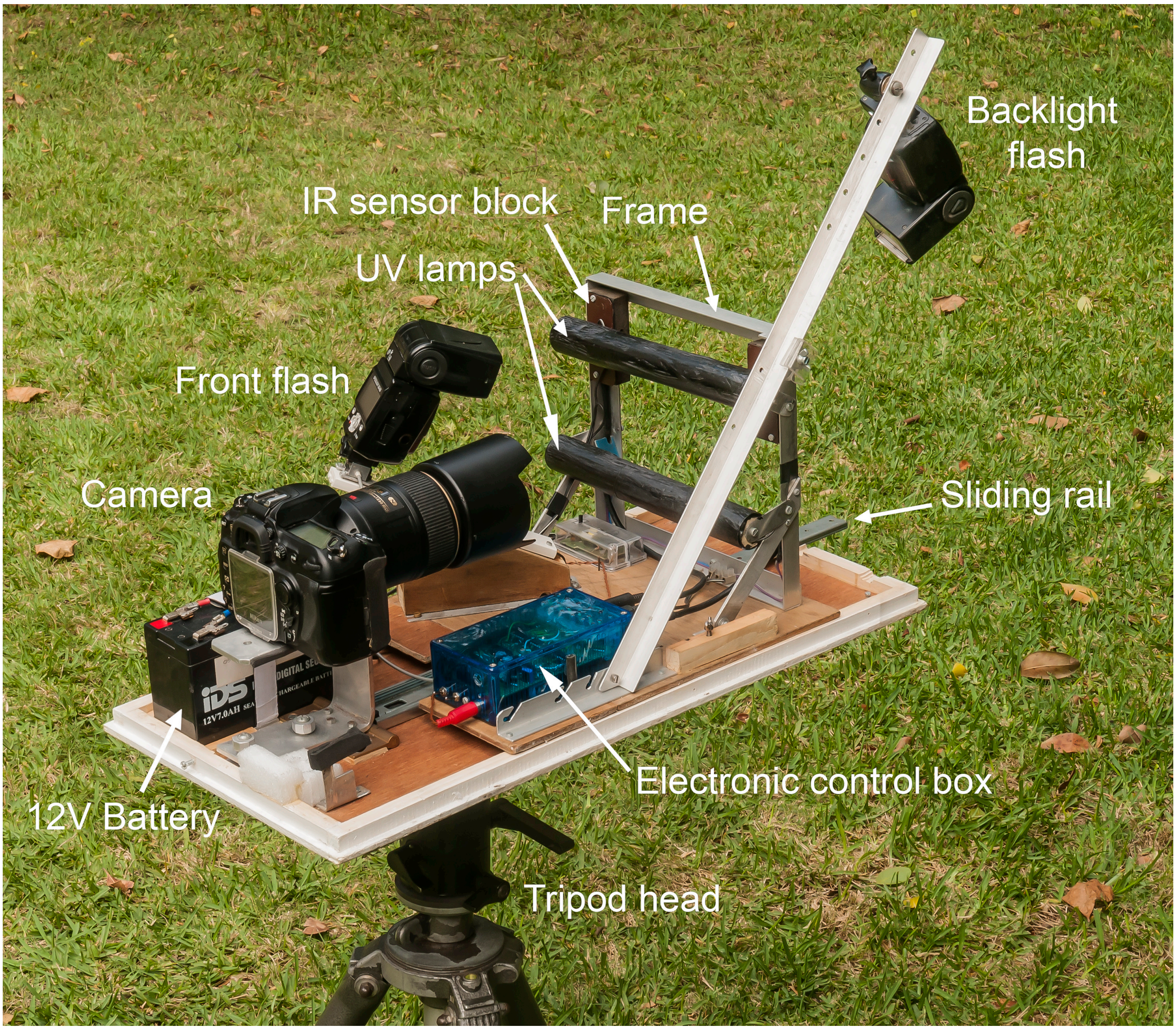

FIGURE 1. The assembled base of the rig with fixed electronic components and connected camera and speedlight flash units ready for use.

A rig designed by a Belgian, Frans Fotoopa (Fotoopa 2010) was used as the basis for a cross-beam photographic shooting rig, now offered commercially by Cognisys (Stopshot 2018). It works on the principle of triggering the system when two intersecting light beams are broken as an insect moves through the intersection point of the beams. The camera, which is fitted with a special high-speed shutter mechanism supplied by Cognisys (2018), triggers the flash. This indirect triggering of the flash makes it necessary to use a high-speed shutter as opposed to those fitted to normal DSLR cameras which impose too much of a delay (e.g., 30 to 50ms) between the beams being broken and the flash firing. Nevertheless, high-speed shutters still impart a significant shutter delay of about 6ms which may result in less precise focus, in comparison to that achieved when firing the flash immediately as the beams are broken (direct flash system) as occurs with the rig described by McIlleron & de Moor (2011). This 6ms delay will result in the flash firing after the insect has moved through the focus point and thus result in fewer sharp images being obtained, particularly for fast flying insects. Faster shutter speeds (down to 3.3ms delay) are possible with costly VS14 or VS25 shutters developed by Vincent Associates (Vincent 2018). An advantage of the indirect system is that it can be used in daylight as the shutter is fast enough to control overexposure by daylight. The Cognisys system has been used by photographers (Zhang 2013) with good results.

While alternative approaches are being used successfully for insect flight photography, the system used by the authors is particularly well suited to photographing Trichoptera and other insects that fly at night or during very low daylight. The other systems referenced do not offer the additional useful information provided by synchronised supplementary lighting. While early versions of the rig were successful in capturing many good images of insects, particularly Trichoptera, in free flight, the system presently used by the authors features considerable improvements to the rigs previously used and described in some detail (McIlleron & de Moor 2011, de Moor & McIlleron 2016).

This paper describes the current form of the rig with emphasis on improvements and illustrating some of the resulting images. These are captured in free flight with the anthropogenic influences limited to the presence of the rig structure, the short duration flash of light from the electronic flash, or LED units, and the presence of ultraviolet light used to attract the insects. These factors, particularly ultraviolet light, may change the pattern of flight of the insect (e.g., changes of flight direction) but do not appear to change their behaviour in other ways (e.g., dynamics of wing movements). The short bursts of light have no observed adverse effect on the flying insect after the flash of light.

FIGURE 2. The base of the rig mounted on a tripod with lid enclosing the assembly for ease of transport and use in the field.

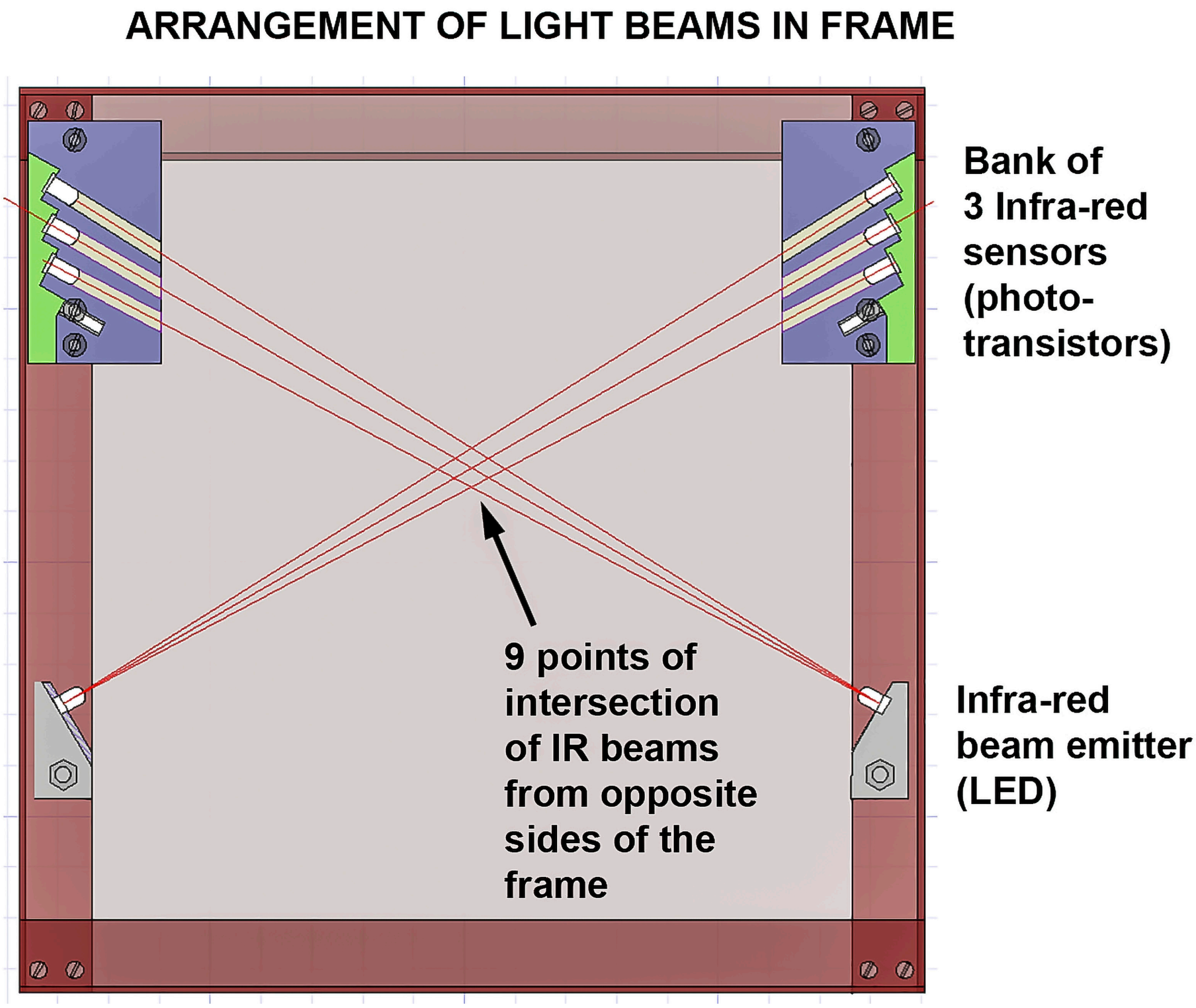

FIGURE 3. Diagram illustrating the frame and light beams arrangement. The camera is focussed on the plane which passes through the 9 points where the light beams intersect near the centre of the frame.

Material and methods, design and use of the rig

1. *Frame on which camera, flashlights and battery are mounted* (*The rig*)

The rig now provides a more robust platform (Fig. 1) on which all the equipment required in the field is mounted, including the camera and flash units. The front section of the base, which supports all the fixed UV lighting equipment, mounting connections for speedlight flash units, and the electronic control box, slides on a rail so that it can be extended to adjust the distance between camera and subject. A 12 V 7AH lead-acid battery is mounted on the rear left side of the platform and the camera is fixed on a rigid central bracket. In the field the complete rig can be placed on a support; for example, on a folding stool or on a strong tripod (Figure 2). For ease of transport and storage, the frame of the rig folds compactly and the rig, (which now excludes only the camera and flashlight units) is packed away in an easily transportable box (Fig. 2).

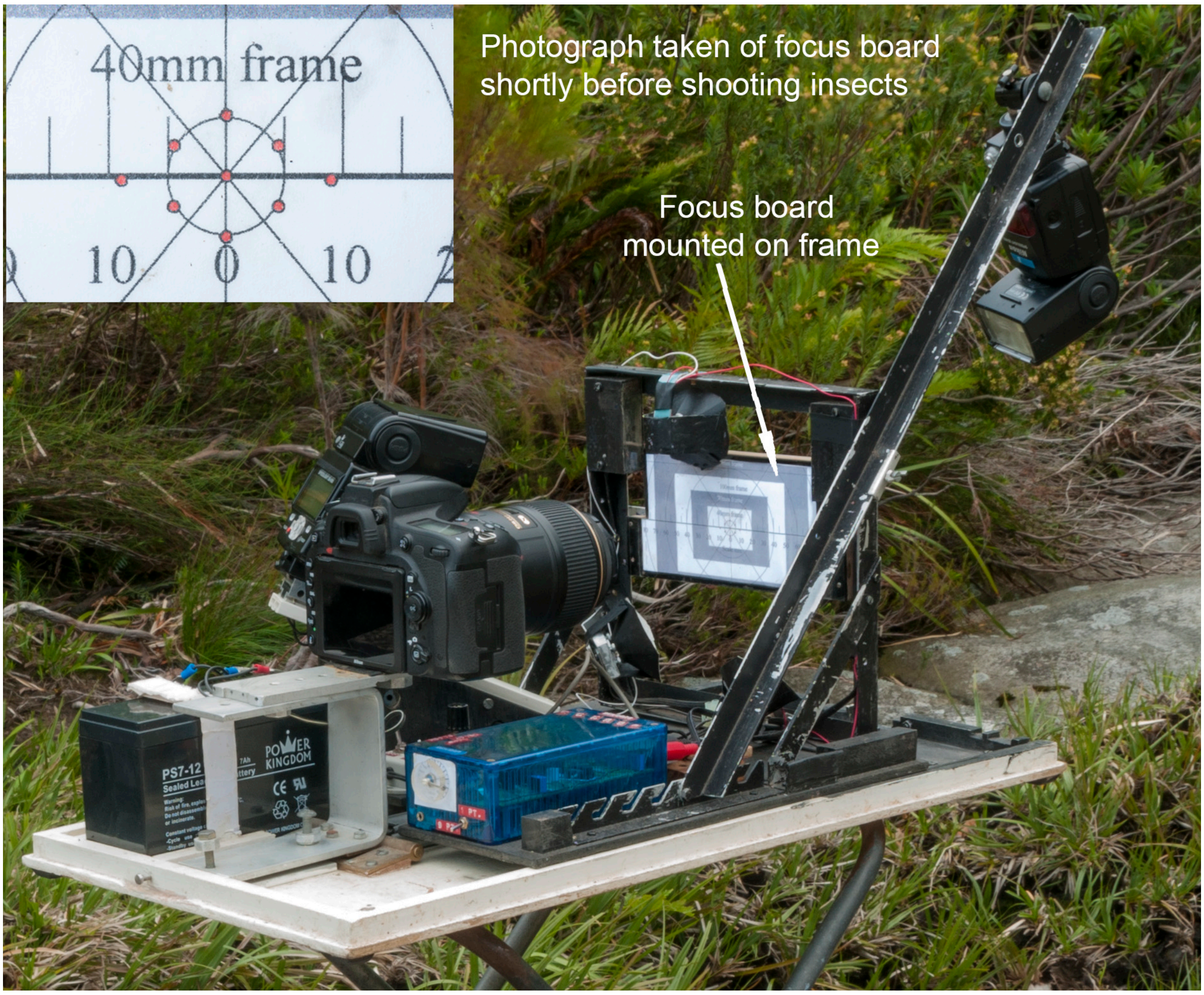

FIGURE 4. The assembled rig with focus board temporarily positioned on the frame for establishing camera settings. The inset image (top left) shows scale markings in mm and nine red dots indicating IR beam intersection points.

2. *Intersecting beams for triggering flash exposure*

Two Laser-beam emitters, which were mounted in a rigid aluminium frame, have been replaced with a pair of infra-red (IR) LEDs and two units each of three IR sensitive photo-transistor sensors (thus making a total of six sensors). There are nine intersection points, any of which is capable of triggering the flash when the intersecting beams are broken (Fig. 3). The logic used in the Electronics Box ensures that the Electronic Flash is triggered only when two beams from opposite sides of the frame are broken simultaneously at one or more of the nine intersection points. Nevertheless, unintended images can be triggered when an intersecting pair of beams is broken simultaneously away from the nine intersection points, e.g., when an insect lands and blocks a beam at one of the sensor units disrupting one or more of the beams while concurrently another insect breaks one or more of the beams entering a sensor on the opposite side of the frame. In such events the flying insect is frequently outside the picture area at the time of the flash firing.

Workshop tests in which a 1 mm diameter wire was swept through the intersection point of the IR beams demonstrated that the beams were sufficiently sensitive to trigger the flash reliably when the wire breaks a beam. This sensitivity has been confirmed in the field by noting that some pictures were triggered by a Trichoptera antenna breaking a beam.

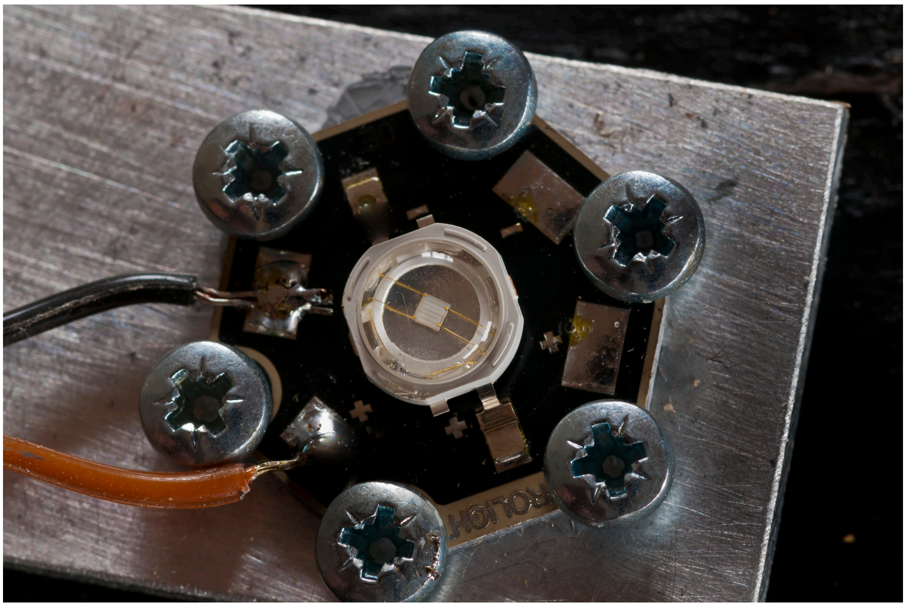

FIGURE 5. Ultraviolet LED used to attract insects to the general location of the frame.

FIGURE 6. *Ecnomus* sp. flying across picture frame captured with flashes set to single flash mode (24 µs, f18, ISO 125 shutter open 7.3 secs).

3. *Setting the focus point and measuring the full frame size prior to photographic session*

Before commencing photography, a focussing board (Fig. 4) is placed temporally on the frame such that it is accurately positioned in the plane of the IR light beams to ensure accurate camera focus. After focussing the camera, a test photograph of the board is taken. The settings on the camera and rig remain unchanged thereafter through the photographic session. The board is marked with a mm scale, which is used to set the desired picture size. By comparing measurements of an insect recorded photographically with the scale on the image of the board, the size of the insect, or parts thereof, can be assessed by displaying both images at the same magnification. Because of the narrow depth of field experienced in the photographs of the insects, the measurement errors attributable to different focus distances is minimal.

4. *Lightsource to attract flying insects*
Ultraviolet (UV) lights are switched on throughout a shooting session to attract the insects to the general location of the rig. These UV lamps can be either Super Actinic fluorescent tubes or LED lights. Both types are in regular use and both operate well. No statistical analysis has been conducted to assess which light source is more effective. Three UV LED's (Prolight 1W, 403nm, up to 350mA) wired in series (Fig. 5) are more efficient, more compact, and simpler to use because they are powered directly by the 12 V battery without the complication of alternating high voltage circuitry used for the fluorescent tubes. Both systems generate unwanted blue light which can degrade the photographic images through fogging (if the camera shutter is kept open longer than necessary to capture an insect image). The UV lights often attract excessively frenetic insect activity which is seldom beneficial for photography. To resolve the fogging of images a simple additional control circuit has been incorporated, which can regulate the power supplied to the UV LEDs, reducing their intensity and associated blue fogging. This is especially pertinent when using high ISO settings (see 9 below).

5. *The electronic speedlight flash*
During standard operation, two electronic speedlight flash units provide front and back lighting of the insect photographed. The electronics-control unit triggers one of the electronic flash units when an insect breaks a pair of intersecting beams. The second flash is triggered simultaneously by a flash slave unit. The electronic flash units are commercially available models: Nikon SB800 with a flash duration of 1/41,600 second (i.e., 24 µs), Nikon SB900 with a flash duration of 1/38,500 second (26 µs), or Nikon SB700 with a flash duration 1/40,000 second (25 µs) when these flash units are set to 1/128th power (manufacturer's manuals). These settings provide the high-intensity, short-duration flash burst needed to capture acceptably sharp images of many insects in free flight (but see 9 below). The flash units are operated in either single-flash mode (Fig. 6) or in repeat mode, i.e. strobe-flash (Fig. 7). In the latter mode an insect appears as a succession of sharp images along its flight path. The distance covered between each image, together with the flash frequency, can be used to estimate the speed of flight of the insect.

FIGURE 7. *Ecnomus* sp. photographed with flashes set to repeat mode at 50Hz (20 ms between flashes, 24 µs, f18, ISO 160, shutter open 11 secs). The average distance flown in this interval is 23.5 mm, which translates into an estimated flight speed of 1.2 m/s. The insect's wingspan estimated from measurements off this photograph is approximately 12 mm.

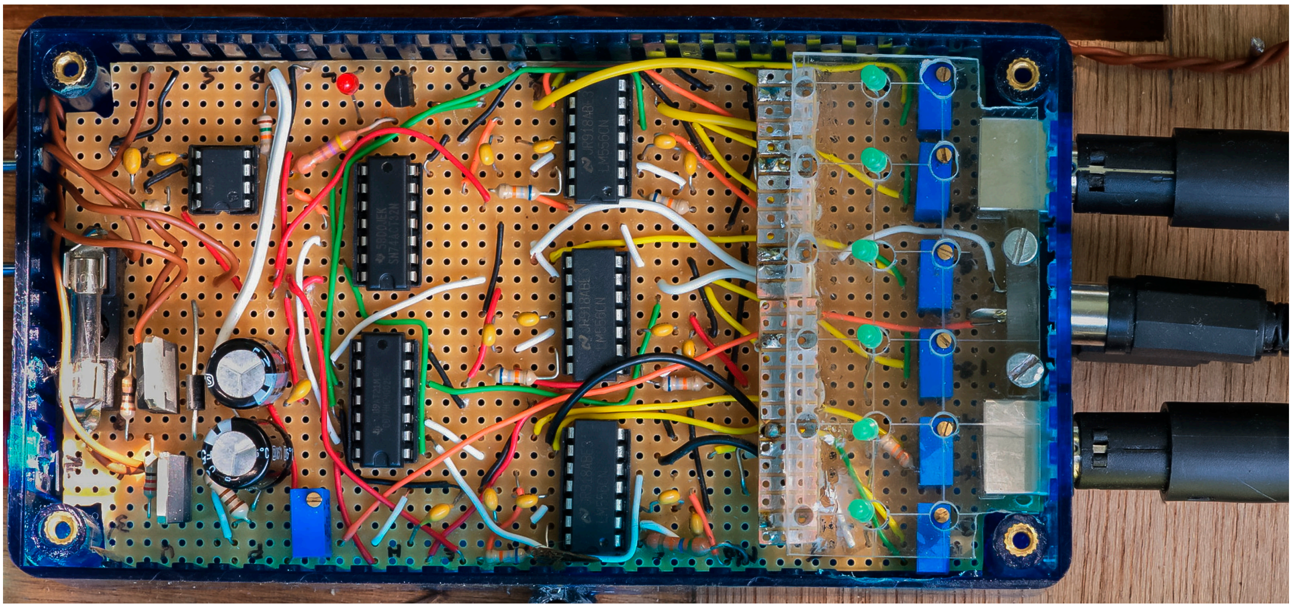

FIGURE 8. Top view of electronics control unit with the lid removed. Note the six green LED lights that glow when a beam is broken.

FIGURE 9. One of the authors operating an older form of the rig beside a river at night. Note the insects, here mainly *Athripsodes bergensis* Scott 1958, and their flight trails in the vicinity of the rig. The insects in this image are revealed by the electronic flash units. The orange trails are revealed by light from an incandescent supplementary lamp.

FIGURE 10. An insect flight trace using incandescent light only. The broad portions of the trace are created during the insect's downstroke. The upstrokes are narrow peaks between the downstrokes. Note orange colour of trace caused by reduced voltage from power drain on battery.

FIGURE 11. Short-duration (24 µs) flash highlights the *Athripsodes bergensis* Scott 1958 sharply, while the yellow LED supplementary light traces the upward flight pattern after this. The broad portions of the trace are when the wings are on the downstroke while the narrow streaks in between are the upstrokes of the wings.

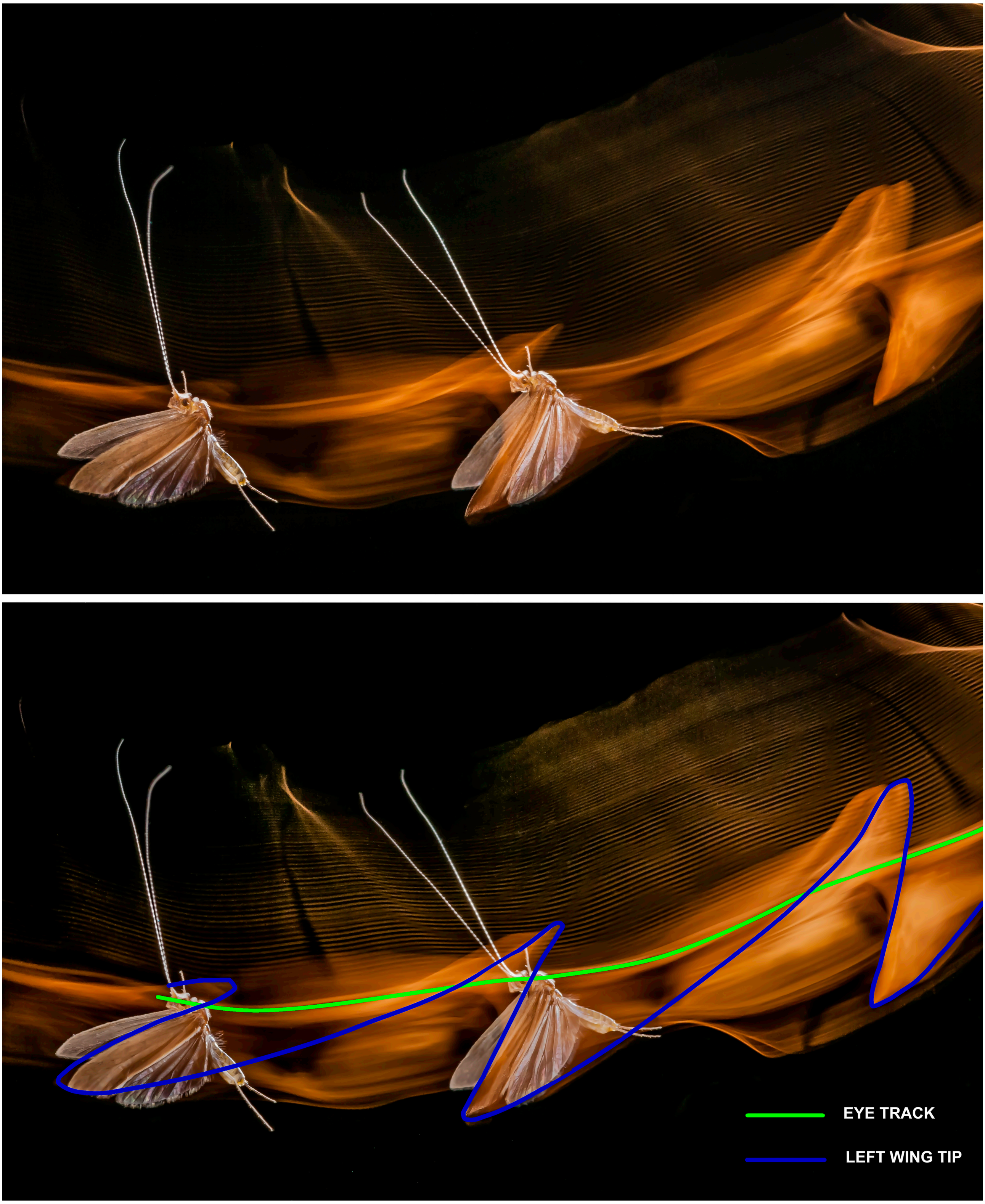

FIGURE 12. 12a, Image of *Athripsodes schoenobates* Barnard 1934 captured with strobe flash (24 µs at 50 Hz) and incandescent supplementary light (shutter exposure 2.5 s). 12b, Image with lines added to highlight the approximate tracks of the eye and left forewing tip. The tightly spaced lines above the insect's head are traces of the nodes on its antenna. Note how the downstroke of the wings is much longer than the short upstroke. During the downstroke the insect moves its wings well forward relative to its body. The reverse happens on the upstroke.

FIGURE 13. Image showing motion blurring in the wings of *Athripsodes bergensis* Scott 1958 at flash duration of 24 µs (f22, ISO 125, shutter open 32 secs).

6. *Electronics control unit*

The electronic circuit design has been revised to process the signal information received from six sensor units (IR phototransistors), compared to the original system in which only two sensors were used. The electronic control unit (Fig. 8) provides circuitry which ensures that an unambiguous (either 'high' or 'low') signal from each phototransistor is fed to logic gates to ensure that the electronic flash units are triggered only when intersecting beams from opposite sides of the rig are simultaneously interrupted. All other signals are ignored (e.g., if only one beam is interrupted, or if two intersecting beams from only one side of the rig are interrupted). The overall delay between the beams being broken and the flash units firing is 10–25 µs and is effectively instantaneous. A green LED is provided for each sensor input signal to indicate to the photographer which beams are being broken. This is useful in tracing malfunction of a particular beam or beams, as happens when, for example, an insect blocks a beam by settling on either an IR LED or sensor unit. The circuitry also imposes a short delay (0.57 seconds) between successive flash firings in order to avoid multiple imaging of a single insect as it passes through the beams.

FIGURE 14. Slow-flying lacewing, Chrysopidae, showing relative sharpness of image (24 µs, f18, ISO 160).

FIGURE 15. Image of *Athripsodes prionii* Scott 1958 captured with Vela One high speed flash (5 µs flash duration, f14, ISO 800) showing fine detail possible at higher flash speeds. Blurring of outer wings is a result of limited depth of field, not motion blur. The image has been severely cropped from the original (see insert of full frame). This degree of sharp detail was not possible with commercially available flash units at 24 µs flash duration.

FIGURE 16. High resolution images captured with Vela one flash at 5 µS, with camera shutter speed of 2.0 seconds to minimise reflected background blue light. 16a, *Athripsodes bergensis* Scott 1958 (f14, ISO 800), note mites on rear of abdomen; 16b, *Chimarra ambulans* Barnard 1934 (f16, ISO 1250).

FIGURE 17. At the high ISO settings needed with Vela One flash, the images are fogged by blue light reflected off insects flying in the background which is only partially mitigated in post processing. 17a, *Athripsodes schoenobates* Barnard 1934 (5 µs, f14, ISO 640 with +1.67 exposure compensation, shutter open 4 seconds); the focus plane passes through the head, front of thorax and near the right front and rear wing tips which are rendered sharp. 17b, *Athripsodes bergensis* Scott 1958 (5 µs, f13, ISO 640 with +1.00 exposure compensation, shutter open 2.1 seconds) showing considerable degradation of the image by blue fogging.

7. *Operation of the camera*

A number of camera models, all DSLRs, each equipped with a high-quality close focus (60 mm or 105 mm f2.8 'macro') lens, have been used. The latest work is being done with a Nikon D850 camera which has a 45 Megapixel sensor which provides fine detail in the images. As with earlier model rigs, the camera is operated (Fig. 9) in manual-focus mode and the shutter is released using a remote release cable with the camera's shutter mode set to 'bulb' (for exception see 9). The shutter is held open until closed manually after an insect has triggered the flash units. The lens aperture is normally set at f16, sometimes down to f22 to achieve acceptable depth of field without suffering significant loss of sharpness. The flashes are placed close enough to the subject to permit the use of low light sensitivity (ISO) settings, typically 100 to 200 ISO.

8. *Supplementary lighting to capture traces of flight*
Supplementary light is relatively long lasting ('continuous') light which can be added to the light from flashlights. The addition of supplementary lighting, unlike flashlight, reveals the flowing traces of the insect's flight. While the insect is not shown sharply by supplementary light, it illustrates the patterns of flight and describes the insect's wing movements (Fig. 10). When supplementary light is combined with flashlight, the insect's image is superimposed synchronously on the flight trace and provides new information and perspectives on flight behaviour and mechanics.

Supplementary lighting was introduced in earlier models of the rig using standard household 150-W quartz/halogen lamps which were switched on and off manually in conjunction with keeping the shutter open. Although some successful images were captured, the supplementary light significantly degraded many images by fogging because of a significant time between switching the supplementary lamp on and off again. Initially the supplementary light was synchronised manually with the insect's passage through the area of the light beam intersections, resulting in far more 'misses' than 'hits' being recorded. The use of this system resulted in an excessive drain of current by the 150-W lamp on the battery and reduced voltage to the lamp, making the insect traces appear orange in colour (Figs 9 & 10). To overcome the 'hit-or-miss' experience the incandescent lamp was replaced with an LED spotlight linked through an electronic control unit to synchronise with the triggering of the flash together with control over the duration of the supplementary light. This configuration resulted in sharp flashlight photographic images, or multiple images when the flashes are set to repeat mode, resulting in images of the insect superimposed on its flight trace (Figs 11 & 12). A further refinement was added thereafter to introduce a controllable short delay, typically a few milliseconds, between the initial flash trigger and switching on of the supplementary light. Thus, a sharp initial image of the insect was obtainable, without the supplementary light superimposing on, and obscuring, the image of the insect. These developments provided images that fully synchronise the superimposed image of the insect with its flight trace, such that the wing position and form of the trace are fully correlated, providing useful visual information relating to wing motion (Figs 12a & 12b). From examination of these images it is clear that, during the downstroke, the wings move well forward relative to the insect's body, while this movement is reversed during the upstroke. The pattern of the wingbeat cycle suggests that the upstroke is much quicker than the downstroke. Higher flash frequencies would test this inference. A further deduction from these images is that the insect's forward motion is slowing down as its body angle steepens relative to its flight path.

9. *Ultra short flash duration*
When closely examined, most images taken with a 24 µs flash duration showed some motion blurring, most pronounced at the extremities of the wings (Fig. 13). Small insects, typically Diptera, with wingbeat frequencies of several hundred Hz, were considerably blurred. For a typical trichopteran [e.g., *Athripsodes bergensis* Scott 1958, with a wingbeat frequency of 60Hz (McIlleron & de Moor 2011) and wingspan of 15mm (Scott 1958)], the calculated average wing tip speed is 2827mm/s (pi*15*60). At this speed the wingtip will move through an arc of about 0.07 mm within a flash duration of 24 µs assuming images are taken at 1:1 magnification on a camera sensor. This figure is about twice the commonly accepted threshold of 0.03 mm used by photographers for a 35 mm film image to be acceptably sharp (Spencer Cox 2018). Other observations (see 8) show that wing-tip trajectory and velocity both vary considerably over a single cycle. These factors would increase the above-mentioned, computed wingtip speed considerably.

Motion blur is seen only in the component of velocity, normal (at right angles) to the optical axis of the camera lens. For photographs of insects flying along the optical axis (i.e., towards or away from the camera), the bodies can be sharp at a flash duration of 24 µs. If the wings of the insect are coincidentally at the extreme top or bottom of their stroke, the motion blur can be relatively little. Slow flying insects with slow wingbeats may also be rendered sharply (Fig. 14). This is in accord with the authors' experience where some insects, including Trichoptera, are rendered sharp at 24 µs. However, carefully examined Trichoptera images photographed with conventional commercial flash units show motion blur within the focus plane of the camera, which is most noticeable at the wingtips.

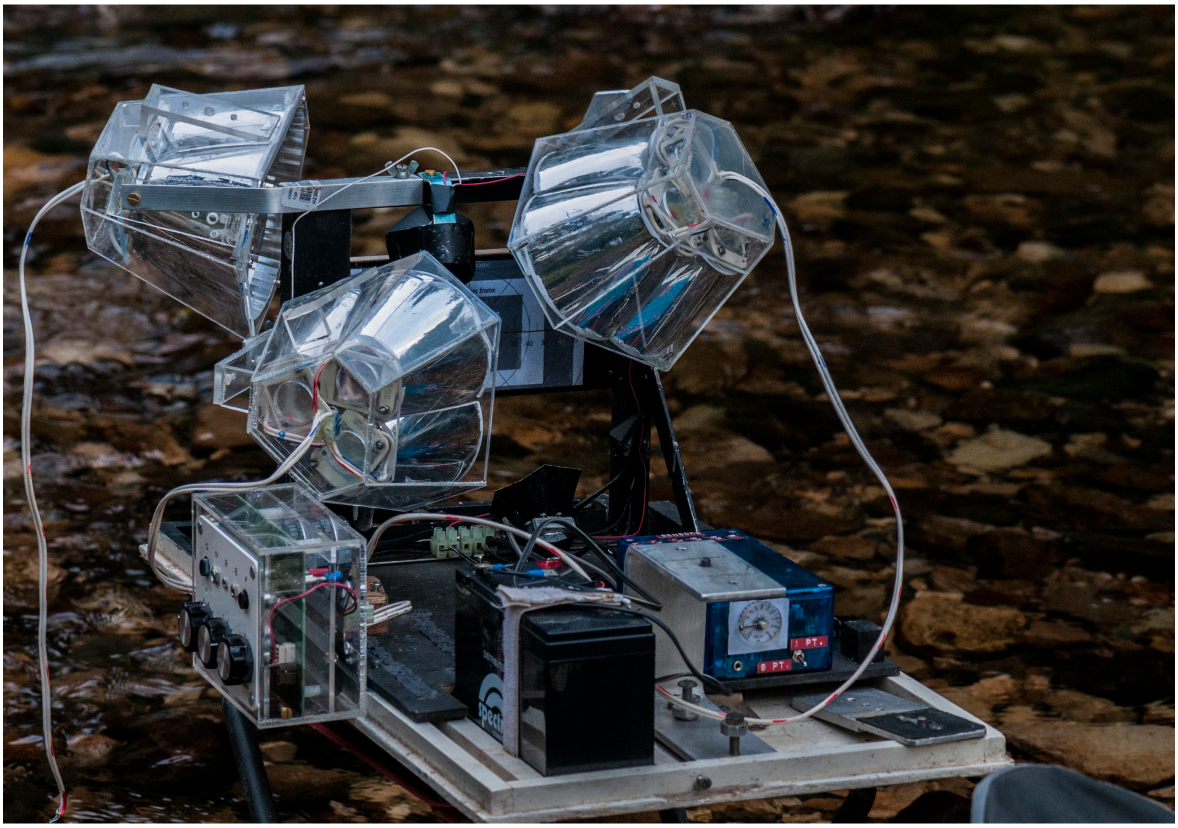

FIGURE 18. The experimental arrangement for testing the Vela One ultra high-speed flash system using three bulky early experimental reflector modules, each with 3 LEDs and associated reflectors. The electronic controller for the Vela One flash is mounted on the left side of the rig.

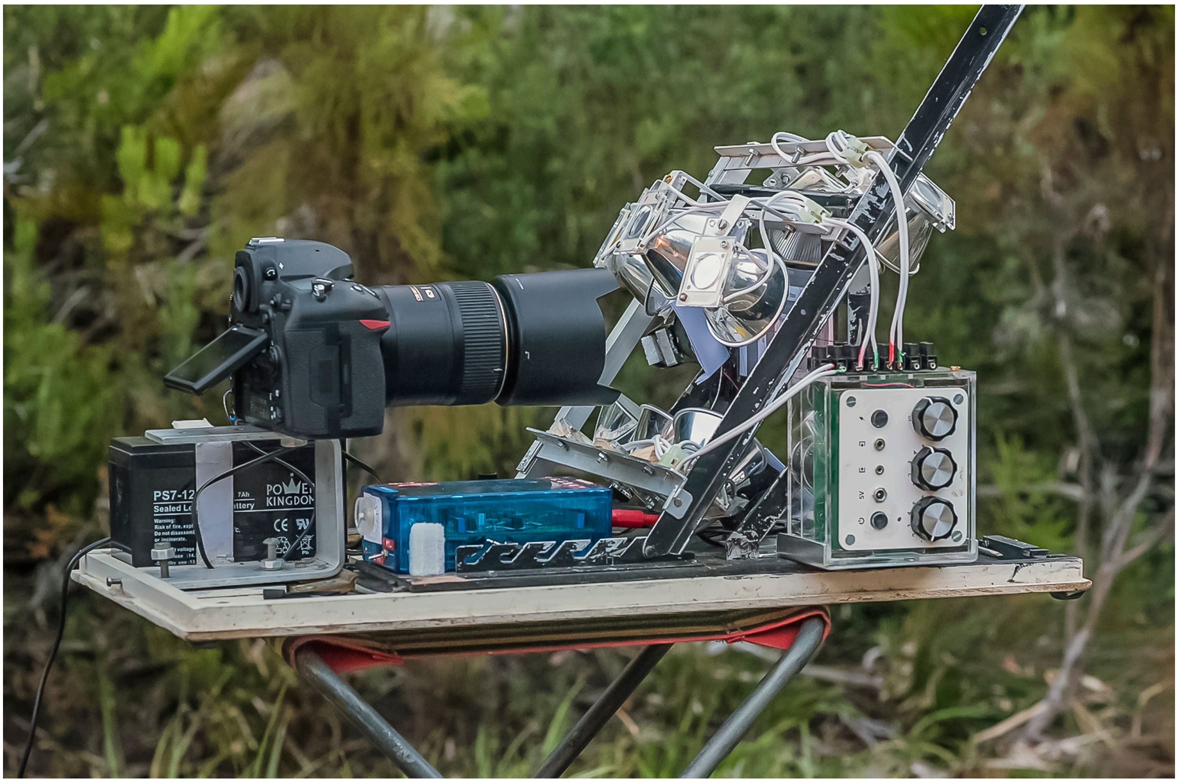

FIGURE 19. Later, more compact design of Vela One flash system, with nine individual smaller reflectors placed to align accurately with targeted picture frame. Note the electronic controller mounted on the right side of the rig.

Alternative higher speed options have been considered. A recent development is to produce a short duration, but intense, LED pulse of light. A 'Vela One' flash unit invented and marketed by Vela labs (Vela One flash 2014-2016) has been adapted for use on the insect rig and is capable of flash durations between 1/200,000s (5 μs) and 1/2,000,000s (500 ns). This unit, after adaptations for use on the rig, has now been tested at 5 μs flash duration on Trichoptera and other insects in the field. This system revealed that the difference in sharpness in the images is considerable (Figs 15–17). However, the Vela One technology has introduced new challenges and significant disadvantages. Chief among these is the low level of light energy emitted compared to current commercial flash units. The adapted unit used nine large light reflectors which were difficult to cluster close to the focal intersection of the beams. New reflector arrangements were organised and fitted in groups of three (Fig. 18). Finally, each reflector was aligned to focus on the area where the IR beams cross, concentrating maximum flash energy as close as possible onto the photo subject area (Fig. 19). In spite of this, high ISO ratings (800 to over 1250) together with wider apertures (e.g., f14 instead of f16 to f22) were needed to illuminate the subject adequately. The sharpness achieved is compromised to some extent by the high ISO settings. The increase in light sensitivity from using high ISO settings also illuminates insects flying in the background causing a blue fogging of the images from the UV lamps. The extent of the fogging, which can be partially mitigated in post processing, significantly degrades the image quality when the shutter is held open for more than two or three seconds. This has led to an operating technique in which the camera shutter speed is set to two seconds duration on auto-frame-advance mode instead of the normal manual duration on 'bulb' setting. The camera then captures an image if an insect triggers the flash within any one of these two-second intervals when the shutter is open. The technique reduces the blue fogging problem but results in many unwanted blank frames.

To further validate the sharpness of the Vela One flash unit at 5 μs, the ratio of sharp to unsharp images has been assessed for a particular photographic session (14 March 2018) using the Vela One flash and another photographic session (16 February 2017) using commercial flashes (Nikon SB800) set at 24 μs duration (1/128 power). In each of the above-mentioned sessions the distance between camera and subject was similar, the number of images sampled was the same (200) and the location of the shoots were in close proximity to each other on the lower Groot River (Nature's Valley). The subjects chosen were mainly *Athripsodes bergensis*, the most common species in this location, or other similarly sized leptocerids. Each image was examined at 100% magnification on a 24" monitor screen. If there was no indication of a plane of sharp focus passing through any part of the image, it was discounted; if the tip of any of the leptocerid's wings was sharp (often indicated by well-defined setae on the wing tip) it was recorded as 'sharp' (flagged green), if not sharp it was recorded as 'unsharp' (flagged red).

The results for the two photographic sessions (each of 200 images) were as follows:

24 μs duration flash (16 February 2017): 7.5% (15 images) with sharp wing tips.
5 μs duration flash (24 March 2018): 35% (70 images) with sharp wing tips.

It was notable that in 100% of the images recorded with 5 μs flash duration, there was some part of the insect (not necessarily a wingtip) that was pin-sharp. This part, together with all other areas within the depth of field were sharp. With the 24 μs duration flash, a significant proportion (approximately 62 %) had no pin-sharp areas visible.

Further developments and improvements to the existing Vela One technology lamps are being researched in order to lower the ISO settings needed. The Vela One flash system is a new technology and further developments in this ultra-high-speed flash technology are expected. In particular, higher power and higher density LED's are fast evolving with continuing improvements being claimed by manufacturers.

The two major limitations to the quality of insect flight images are sharpness and limited depth of field. Whereas new high-speed flash systems offer a way forward for improving sharpness, the depth of field issue is more intractable. The relatively high magnification involved in photographing close-up images of insects has rendered much of the insect 'unsharp' outside the sharp zone (depth of field). Whereas depth of field is widened by using smaller apertures (higher f-stop numbers), the image sharpness becomes increasingly compromised as the aperture is reduced beyond about f16 through diffraction of light. This is an optical phenomenon that cannot be readily reversed. Accordingly, none of the images presented in this paper are captured at apertures smaller than f22 and those using the Vela One flash are at f14, the wider aperture chosen to mitigate the high ISO problem.

One practical way in which depth of field can be widened is to increase the subject to camera distance. However, the insect would be smaller in relation to the frame and, in this way, the image quality would be compromised, especially if cropped to compensate for increased frame size. An alternative is to use a camera with a smaller sensor to provide greater depth of field. This is a realistic approach because of improvements in quality available in smaller-format cameras.

FIGURE 20. Image of ?*Parecnomina resima* Morse 1974 taken with Vela One Flash (5 µs, f16, ISO 1250) using precision focussing.

FIGURE 21. Strobe flash mode image of *Chimarra ambulans* Barnard 1934 at 50 Hz (24 µs, f16, ISO 200, Shutter open 15 seconds). The close similarity of wing position in each strobe image indicates chance synchronisation between flash and wingbeat frequencies.

FIGURE 22. Combination of strobe and trace modes reveals a busy flight scene with *Athripsodes bergensis* Scott 1958 highlighted by strobe images superimposed over its flight trace (Flash 24 µs, 50 Hz, shutter open 1.2 s, f22, ISO 200). From measurements off this image, average flight speed is calculated as 0.4 m/s and wing beat frequency approximately 40 cycles/s.

Conclusions

The rig for photographing insects in flight has been improved considerably as explained in the features listed below.

1. A comprehensive unit combining in one box all the requirements for use in the field, only the camera and flash units need to be carried separately. It is robust, readily unfolded or packed away, easily carried and transported, reliable, and proven to withstand rough conditions.
2. images can be captured in several modes for revealing a range of useful information as described below.
    a. Good quality single images with focussing precision, accurate to less than 1 mm (Fig. 20). Such images are useful for display purposes as an aid to field identification and to reveal wing mechanics, particularly when a number of images of the same species with wings in different positions are examined.
    b. Strobe flash can capture a succession of images of the insect along its flight path which can be used to estimate the insect's flight speed and examine flight mechanics (Fig. 21).
    c. Flight trace images in which the insect 'traces' its own pattern of flight, showing well-defined wing beat cycles which can be analysed for information on flight mechanics (Figs 10 & 11).
    d. Combinations of the three above-mentioned modes (Figs 12a, 12b & 22) can produce relatively sharp flash images that may be superimposed on the insect's flight trace. Since the flight trace and flash images are fully correlated, the pattern of wing movement and flight mechanics can be better understood.
    e. The rig described here is cost effective and particularly well-suited to photography of insects that fly in low light (night or dusk), including most Trichoptera and Lepidoptera.
3. The revised rig is a useful and flexible tool for researchers and enthusiasts as well as for creating attractive, often aesthetically beautiful, photographs for display.

Acknowledgements

We acknowledge the help of institutions that made funding available for research, equipment, and travel assistance: The National Research Foundation (NRF) Incentive funding for rated researchers, a Rhodes University Joint Research Committee Grant. The Directorate of Museums and Heritage, Eastern Cape, is thanked for providing research facilities and encouraging this research. Willie Dalgleish is thanked for providing figure 19, all other figures were provided by the first author. Irene de Moor is thanked for editorial comments which improved this paper.

References

Cognysis (2019) *Capturing Insects in Flight with the Insect Rig*. Available from: https://www.cognisys-inc.com/how-to/high-speed-shutter/flying_insects.php (accessed on 20 December 2019).

Cox, S. (2019) *Hyperfocal Distance Explained*. Available from: https://photographylife.com/landscapes/hyperfocal-distance-explained (item 3) (accessed 20 December 2019).

de Moor F.C. & McIlleron W.G. (2016) Preliminary observations of flight activity of Trichoptera in the southern Cape, South Africa. *Proceedings of the 14th International Symposium on Trichoptera.* Magnolia Press, New Zealand. *Zoosymposia* 10**,** 172–187. https://doi.org/10.11646/zoosymposia.10.1.14

Fotoopa, F. (2010) "*Photo Grandpa*" *Shoots with Laser Rigs*. Available from: https://petapixel.com/2010/02/05/photo-grandpa-shoots-with-laser-rigs/ and: https://www.flickr.com/photos/fotoopa_hs/4388030248/in/album-72157622681513885/ (both accessed 20 December 2019)

Fox, J. (2013) "*Insects In Flight – Macro Photography Special*" Available from: https://digitalphotographycourses.co.za/insects-flight-macro-photography-special/ (accessed 25 January 2020)

McIlleron, W.G. & de Moor, F.C. (2011) Photography of Trichoptera (Insecta) in flight. *Proceedings of the 13th International Symposium on Trichoptera*. Magnolia Press, New Zealand. *Zoosymposia*, 5, 297–318. https://doi.org/10.11646/zoosymposia.5.1.23

Scott, K.M.F. (1958) Some new caddis flies (Trichoptera) from the Western Cape Province—2. *Annals of the South African Museum*, 44, 39–52.

Stopshot (2018) *High Speed Photography—StopShot*. Available from: https://www.cognisys-inc.com/products/stopshot/stopshot.php (accessed 20 December 2019)

Vela One Flash (2014–2016) *Your Shots Are Too Slow—We're FixingThat*. Available from: https://www.vela.io/ (accessed 20 December 2019)

Vincent (2018) *Optical Shutters*. Available from: https://www.uniblitz.com/product-category/optical-shutters/ (accessed 20 December 2019)

Zhang, M. (2013) *Photos of Insects in Flight Captured with a Custom Laser Beam Camera Rig*. Available from: https://petapixel.com/2013/04/18/photos-of-insects-in-flight-captured-with-a-custom-laser-beam-camera-rig/ (accessed 20 December 2019)