An Update of Commercial Infrared Sensing and Imaging Instruments

Herbert Kaplan

Honeyhill Technical Company
193 East Avenue, Norwalk, Connecticut, 06855

Abstract

This paper will begin with a classification of infrared sensing instruments by type and application, listing commercially available instruments, from single point thermal probes, to on-line control sensors, to high speeed, high resolution imaging systems.

A review of performance specifications will follow, along with a discussion of typical thermographic display approaches utilized by various imager manufacturers.

The paper will conclude with an update report on new instruments, new display techniques and newly introduced features of existing instrumemnts.

Classification of Instruments

Infrared sensing instruments are traditionally classified into three categories:

A. Spot Measuring
B. Line Scanning
C. Thermographic (Two Dimensional Scanning)

Spot measuring devices collect radiant energy from a spot or area on a target surface and provide an indication of radiance, or infer a temperature based on the energy from that spot which produces an electrical response from the instrument's detector. Line scanning instruments provide an output, generally an analog trace, of the radiant energy (or, in ideal cases, temperature) distribution along a single straight line projection from the target surface. Thermographic instruments provide an image of the energy distribution over a scanned area on the target surface. This is presented in the form of an intensity-modulated black and white picture or a synthesized color display.

Categories A. and C. can be further divided into three groups each and this paper will review commercially available instruments along the line of this further breakdown:

A. Spot Measuring
    1. Probes
    2. Portable Hand-held
    3. On-line (Monitoring and Control)

B. Line Scanning

C. Thermographic
    1. Thermal Viewers
    2. Pyrovidicon Imagers
    3. Thermal Raster Scanners (Imaging Radiometers)

PRECEDING PAGE BLANK NOT FILMED

Instrument Manufacturers

Particularly in Category A. there are many companies offering the same instrument under different private label arrangements. In order to avoid duplication, only the original manufacturer or prime distributor will be listed wherever possible.

The charts of Table 1. provide a tabulation of all instruments known to the author on which descriptive literature was available at the time of preparation of this paper. Table 2. is a listing of current addresses and phone numbers of equipment manufacturers listed in Table 1. Table 3. is reprinted from paper 371-01 (H. Kaplan, Thermosense V) and summarizes proven industrial applications for thermal sensing and imaging instruments. The following discussions will highlight the applications for which each instrument category and group is particularly suited based on configuration or performance characteristics.

Discussion of Instruments

A. Spot Measuring

1. Probes

Temperature probes are the most recent addition to the spot measuring category. They are characterized by low price (from $350 to $1,000), pocket-portability and wide collecting angle. They are battery powered and are generallly optically pre-adjusted for minimum spot size at short working distance; a 1/4" spot at a 3/4" working distance is typical. Some models are designed to operate into a conventional multimeter and some incorporate their own readout box with an LCD display. They usually feature disposable batteries and some models have AC adapters. Temperature ranges are from about zero°F., or slightly below, to +600°F. and a sensitivity of 1°F is easily achieved. Emissivity adjustments are available on some models.

Probes are ideal for close-up measurements and find applications in circuit board analysis, trouble shooting of electrical connections, inspection of plumbing systems and, most recently, application to biological and medical studies.

2. Portable Hand-held

With few exceptions these instruments are pistol-shaped and designed for middle distance measurements. They are usually optically preadjusted for infinity focus. A typical 2 degree field of view resolves a 3" spot at a 60" working distance and a 1' spot at a 30' working distance. Prices range from about $500 to more than $3,500. Sighting and aiming methods vary from simple aiming notches to enclosed illuminated reticles. There are instruments with extremely narrow fields of view (0.5°) that include a rifle stock and telescopic sight. Most instruments in this group incorporate emissivity adjustments and some include microcomputers with limited memory. Most are available with a recorder output, although this feature is seldom used. A meter is always provided and, with one exception that reads in BTU/Sq.Ft./Hr., the readout is always in temperature units. Analog displays are still available, although decreasing in popularity. Digital readouts featuring LED's were first introduced about 12 years ago, but the LCD display, introduced more recently, is more in demand, mainly because its tiny power drain extends battery life. For this reason the more recent instruments offer replaceable rather than rechargeable batteries and battery life approaches one year. Some instruments in this group have zeroing adjustments, but all of the newer instruments include auto-zeroing features. Temperature ranges are, typically, from -20 to 2000°F. Temperature sensitivity and readability are usually 1° (F or C) or 1% of scale, although sensitivities on the order of 0.1°F are achievable.

This instrument group is particularly suited to applications where spot checking of target temperatures is sufficient and continuous monitoring is not required. A typical use would be for periodic maintenance checks of rotating machinery to detect whether or not bearings are beginning to overheat. These instruments, over the past few years, have become an important part of many plant energy conservation programs, but are equally useful in checking mix temperatures of food products, cosmetics and industrial solvents. Although many of these instruments provide extremely accurate readings, this feature, like the recorder output, is less important to the user than repeatability, ruggedness, portability, reliability and ease of use.

3. On-line (Monitoring and Control)

The one feature that distinguishes this instrument group from the others is decidated use. The instrument is generally mounted where it can measure the temperature of one specific target, and remains there for the life of the instrument or the process. With few exceptions, these instruments operate on line power. The ouptut signal of the instrument can be observed on a meter, used to operate a switch or relay, feed a simple or sophisticated process control loop, or be used in any combination of these functions.

Early on-line instruments consisted of an optical sensing head and an electronics/control readout unit at the other end of an interconnecting cable. This configuration still exists to some extent, but most of the newer units feature sensing heads that are more stable electronically, and hence more independent of the remote control units. The trend is for these new sensors to mate with universal indicator/control units that accept inputs from various types of industrial sensors.

Because this instrument group is selected to perform a specific task, a "Shopping List" format is provided the customer by the manufacturer in order that all required features can be purchased.

Manufacturers offer sensing head features such as variable or fixed focus, sighting tubes, "light pipes", water-coolable housings, air purge fittings, air curtain devices and see-thru aiming with target-defining reticles. The "Shopping List" for the indicator/controller unit might include digital readout, BCD output, analog output, single, double, or proportional set point, rate signals, sample and hold, peak or valley sensor and datalogger interface. Emissivity controls, located in a prominent place on a general purpose instrument, are more likely to be located behind a bezel on the sensor on these dedicated units, where they are set one time and locked.

Spectral characteristics are worth mentioning separately, although, technically, they are part of the sensing head "Shopping List". The spectral interval over which the sensing head operates is selected to optimize the signal from the target, to reduce or eliminate the effect of an interfering energy source, or to enable the instrument to measure the surface temperature of thin films of material that are largely transparent to infrared energy. This last application has made these instruments important factors in the manufacture of thin film plastics and also of glass.

Two-color or "ratio" pyrometers are one special case of the on-line instrument. These are particularly useful in high temperature applications, in measuring small targets. The emittance of the target need not be known providing it is constant and reflections are controlled. The target need not fill the field of view providing the background is cool, constant and uniform. Also, impurities in the optical path resulting in broad band absorption do not effect the measurement, since the measurement is based on the ratio of energy in two spectral bands.

Another special case is the fiber optic-coupled thermometer, where inaccessible targets can be measured by replacing the optic with a flexible or rigid fiber optic bundle. This, of course, limits the spectral performance, and hence the temperature range to the higher values, but it has allowed temperature measurements to be made when, previously, none were possible.

The infrared microscope is a third special case. This instrument is configured like a conventional microscope and, through the use of reflective microscope objectives and beam splitters, it enables the operator to simultaneously view and measure targets down to 0.0003"in diameter with an accuracy of about 0.5°F.

Most recently another special case known as the "laser pyrometer" has been introduced. This instrument uses the reflected energy of an active laser to measure target reflectance. A built-in microcomputer calculates target emittance and uses this to provide a corrected "true temperature" reading. The laser pyrometer is useful for high temperature diffuse target surfaces.

Prices of instruments in the on-line control instrument group vary from about $1,000 for an "infrared switch", to more than $13,000 for infrared microscopes and on-line instruments equipped with many control features. Generally speaking, the price goes up when sensitivity, small spot size and speed of response are all required, and, of course, when many "Shopping List" items are added.

B. Line Scanners

The purpose of spatial scanning is to derive information concerning the distribution of radiant energy over a target scene. Quite often a single straight line scanned on the target is all that is necessary to locate a critical thermal anomaly. The instantaneous position of the scanning element is usually controlled or sensed by an encoder or potentiometer so that the radiometric output signal can be accompanied by a position signal output and be displayed on a chart recorder, an oscilloscope or some other recording device. All commercially available single line scanners scan in object space so that wide angle scanning can be accomplished. Probably the first approach to line scanning adopted commercially was in an aerial-type thermal mapper in which the line scanner was mounted on a moving vehicle and scanned lines normal to the direction of motion. The outputs representing these individual scan lines were intensity-modulated and serially displayed in shades of gray on a strip map, representing the thermal map of the surface being overflown by the vehicle.

A portable line scanner, widely used commercially, scans a single line on target, develops a visible "temperature trace" using light emitting diodes and, by means of optical beam splitting techniques, superimposes this trace over the visible scene viewed by the operator. The operator selects the line to be scanned by aiming the instrument's horizontal center line. Photorecording of the composite scene is accomplished by aiming a conventional instant color camera through the eyepiece of the scanner. This instrument has no recorder output and is, therefore, not suitable for process control applications. Unlike most thermal viewers, however, (see next section) absolute temperatures are obtainable with this device. Good applications for this line scanner include electrical switchgear and tranmission lines, plumbing systems trouble-shooting and web process profiling.

A more modern, high speed commercial scanner develops a high resolution thermal map by scanning normal to the motion of a moving target such as paper web or a strip steel process. The output signal information is in real-time computer compatible format and can be used to monitor, control or predict the behavior of the target. The best applications for this scanner are in on-line real-time process monitoring and control.

C. Thermographic

An important advantage of radiation thermometers over contact thermometers is their speed of response. The measured energy travels from the target to the sensor at the speed of light. The response of the instrument can then be in milliseconds or even microseconds. This important feature has allowed the field of infrared radiation thermometry to expand into real time thermal scanning and thermal mapping. When problems in temperature monitoring and control cannot be solved by the measurement of one or several discrete points on a target surface it becomes necessary to spatially scan, that is to move the collecting beam (instantaneous field of view) of the instrument relative to the target. This can be done by moving the target with the instrument fixed or by moving (translating or panning) the instrument, but is more practically accomplished by inserting movable optical elements into the collected beam.

The purpose of spatial scanning is to derive information concerning the distribution of infrared radiant energy over a target scene. The detector output is intensity-modulated in proportion to the total exitant radiant energy at each point so scanned on the target surface, and the image produced is presented in monochrome or color where the gray shades or color hue are intended to represent a thermal level at the target surface. These thermal images are called *thermograms.*

Although an almost infinite variety of scanning patterns can be generated using two moving elements, the most common pattern is rectilinear, and this is most often accomplished by two elements each scanning a line normal to the other. A typical rectilinear scanner employs two rotating prisms behind the primary lens system (refractive scanning). An alternate approach to scanning uses two oscillating mirrors behind the primary lens (reflective scanning). This is also commonly used in commercially available scanners, as are combinations of reflective and refractive scanning elements. Another approach to thermal imaging is the pyrovidicon, or thermal video system, where scanning is accomplished electronically. Both rectilinear and electronic scanners will be discussed.

Classification of thermographic (thermal imaging) instruments

Commercial thermal imaging systems fall into three categories as follows:

1. Thermal viewers
2. Pyrovidicon imagers
3. Thermographic raster scanners (imaging radiometers)

The charts of Table 1. provide a listing of all instruments known to the author on which descriptive literature was available at the time of preparation of this paper. Table 2. is a listing of current addresses and phone numbers of equipment manufacturers listed in Table 1. Table 3. summarizes proven industrial applications for thermal imaging instruments. The following discussions will highlight the applications for which each instrument category and group is particularly suited based on configuration or performance characteristics.

Discussion of instruments

1.Thermal viewers

Thermal viewers are inexpensive ($10,000 to $14,000) battery powered scanning instruments producing a qualitative image of the (thermally associated) radiant exitance distribution over the surface of a target. The battery packs are rechargeable and usually provide 2-3 hours of continuous operation. These are one piece, lightweight instruments designed to be simple to operate. The first thermal viewers required cryogenic cooling of the detector elements accomplished by means of a small tank of compressed argon. Newer units feature thermoelectric detector cooling provided by a battery powered cooler.

Thermal viewers were not designed for absolute temperature measurements, but they can demonstrably sense temperature differences of tenths of degrees. Some manufacturers have modified thermal viewers and introduced absolute temperature references so that absolute measurements are possible in certain applications. This generallly requires an additional box, however, and diminishes the portability that defines the instrument group. (It also increases the price). Thermal viewers operate most effectively with cooler targets (0-200°F.) but, through the use of optical attenuators, they can be used for targets up to 2000°F. Typically, the area scanned (field of view) of thermal imagers is from 6 to 8 degrees high and from 12 to 18 degrees wide, with spatial resolution (instantaneous spot size) of 2 milliradians (0.1" at 5 feet). A hard copy of the thermal image is acquired by through-the-eyepiece recording using either conventional or Polaroid film.

Applications for thermal viewers fall into virtually all the areas listed in Table 3. but are limited to those in which the temperature measurements are not critical and recording quality need not be optimum. The combination of a thermal viewer (to locate thermal anomalies) and a hand-held thermometer (to quantify them) is a powerful and cost-effective one. Thermal viewers are particularly useful industrially in tight spaces or, conversely, when a sizable area must be traversed and user fatigue becomes a factor.

2. Pyrovidicon imagers

Pyrovidicon imaging systems are not unlike home videorecording systems except that the camera tube is a pyroelectric vidicon (pyrovidicon) rather than a conventional vidicon, and records target radiation in the infrared rather than the visible spectrum. The significant difference is that the pyrovidicon has no dc response; that is, if the camera is not continuously panned over the target, or the collecting beam optically "chopped", the image fades from the screen. This behavior is caused by the fundamental photoelectric response characteristics of the detector material. Aside from the tube, which is rather costly, and the lens, which is generally germanium and also costly, these systems utilize commercially available television equipment and recording accessories. The price of a complete pyrovidicon recording system is as low as $13,000.

By comparison with other infrared imaging systems, the picture quality and resolution are good, approaching conventional TV format. The thermal image can be viewed or videotaped with equal convenience, and no cooling is required. The requirement for continuous target panning can be made less objectionable by the ability to play back an image and freeze the frame for detailed image inspection. Mechanical "chopper" options are offered by most instrument manufacturers, but, except for the very costly "synchronous choppers", they degrade image quality and thermal resolution. Pyrovidicon systems do not offer absolute measurement capability, but a thermal profile feature, available on some units, provides an analog of the center scan line displayed to the side of the image. Also, one manufacturer offers a model in which a spot measuring sensor is boresighted with the scanner and its measurement is superimposed on the video display along with a defining reticle in the center of the display. Thermal resolution of these instruments is between 0.2 and 0.4 F. in panned mode and double that (half as good) in "chopped" mode.

Pyrovidicon systems are particularly suited to moving targets, airborne scanning and distant measurements. They operate well in the 8-14 micron atmospheric transmission window. They are susceptible to momentary loss of sensitivity from saturation phenomena known as "depoling" when suddenly aimed at very hot targets with the aperture improperly open, and the automatic repoling circuits require about a 30 second restoration time, resulting in some operator inconvenience. Operating costs are very low since no coolant is required and common, erasable videocassettes are used for recording purposes. Videotapes can be monitored on conventional television receivers.

3. Thermographic raster scanners (imaging radiometers)

Thermographic scanners (also called imaging radiometers) constitute the "top-of-the-line" of commercial thermographic instruments. They provide potentially quantitative temperature measuring capability and high resolution image quality. Cryogenic detector cooling is often required and this is usually done with liquid nitrogen. Most commercially available thermographic scanners use a single detector but some manufacturers offer dual-detector or multidetector instruments. Some multielement systems are offered at a premium price, for special applications such as high resolution aerial mapping and search. These are commercial versions of military FLIR (forward-looking infrared) systems used in night vision and surveillance applications.

Thermographic scanners use refractive, reflective or hybrid scanning systems and operate in either the 3-5 or the 8-14 atmospheric window. In addition to quantitative temperature measuring capability in idealized circumstances, these instruments feature excellent capabilities for both spatial resolution (about 1 milliradian) and minimum resolvable temperature (0.05 to 0.1°C). Most manufacturers offer isotherm graphics features, spectral filtering, interchangeable optics for different total fields of view, color or black and white displays, flexible videorecording capabilities and computer compatibility. Most general purpose systems in use today feature compact, field-portable, battery-operable sensing heads and control/display units. A complete system, including battery and videorecorder can usually be handled by one person, by either mounting the components on a cart or assembling them on a personal harness arrangement. Some special purpose systems are not so configured. The Barnes CompuTherm, intended for the thermal examination of microcircuit chips and other small devices, is arranged in a bench type configuration. The Inframetrics IRAMS, the Hughes ThermaScan and the UTI 9000, designed for testing of printed circuit boards and similar targets, are also made to be integrated into a test bench with automatic test equipment.

Base prices range from $20,000 to $40,000 for basic field portable scanners and up to $70,000 for special high resolution FLIR-type scanners (Commercial FLIR systems). The addition of computer based diagnostic software packages can increase the price to well in excess of $100,000.

Recent trends

Several new features and new options have been touched upon in previous sections. The most recent of these will be highlighted in this section.

In the point sensing category, the probe sensor suitable for mating with a conventional multimeter was introduced by Linear Laboratories. Dickson and Testaterm offer similar units.

Telatemp and Everest offer laser and light beam aiming accessories similar to the feature offered by Mikron on some of its hand-held models. Several manufacturers added linearized outputs to their on-line units and more high quality modular sensors have become available. Several manufacturers offer reticle sighting with temperature display projected into the viewer. Microprocessors have been added to hand-held units, such as the Raytek PM series; these provide limited memory for on-site datalogging and "max, min, mean" storage.

Within the last few years many imports, specifically from Japan, have been introduced in the United States. Hand held thermometers by, Chico, Horiba and Optex are being distributed by various US manufacturers. Introduction of on-line control sensors from these manufacturers will probably follow.

In the thermographic category, pyrovidicon systems have come down slightly in price, reflecting the somewhat reduced costs of lenses and tubes. ISI has introduced models incorporating a built-in boresighted radiation thermometer and limited microprocessor-based diagnostics. Inframetrics recently offered their model 522L scanning radiometer at a new base price under $20,000, which may compete effectively with the pyrovidicons. Early in 1986 the AGEMA 870, the first commercially-available non-cryogenically cooled thermographic scanner was introduced. This system uses a "SPRITE" type thermoelectrically-cooled detector operating at 195°K., and offers performance generally equivalent to other "top-of-the-line" scanners at about the same price. This is an important development in that it eliminates the most commonly encountered objection among users of thermographic scanners; that is, the need to frequently refill or recharge cryogenic devices and to have the necessary supplies on hand. Hughes Aircraft Company introduced the series 7000, a competitive thermoelectrically-cooled multidetector scanner, in 1987. It is reasonable to expect that, in the not-too-distant future, all thermographic scanners intended for field use will not require cryogenic cooling. The most recent entry, as of this writing, is the AGEMA 450, which is a "camcorder" type scanner with the sensing head (including thermoelectrically-cooled detector), control electronics and eyepiece video display integrated into a single shoulder-mounted unit.

Clearly the most dramatic recent development in the use of thermographic raster scanners has been the introduction of computer-assisted thermal image storage and processing, causing thermographic scanning to become a far more exact science and greatly expanding its usefulness. Innovative software has been tailored specifically for detailed image and thermal data analysis, and has been rapidly updated and expanded. This capability is generally offered separately from the basic scanning instrument, although some limited diagnostic software is usually included in the basic package for on-site analysis. Most software packages for thermographic image analysis and diagnostics offer features that include spot temperature readout, multiple X and Y analog traces, image shift, rotation and magnification, area analysis with histogram display, image averaging and filtering and permanent disk storage.

Perhaps the single most powerful feature of these new routines is the capability for archiving thermal images of acceptable components, assemblies and mechanisms, and using these stored images as models for comparison to subsequently produced items. Subtractive routines produce differential images illustrating the deviation of each pixel (picture element) from its corresponding model. Another powerful routine recently introduced by Barnes Engineering Division, EDO Corporation, is a spatial emittance determination and correction program which produces true surface temperature thermograms of microelectronics devices and other very small targets. To perform this function, the unpowered device is heated sequentially to two known, low level temperatures and the stored thermal images are used to allow the computer to calculate the emittance of the object space area viewed by each pixel. The device is then powered and the image produced is corrected, point-by-point, for the emittances previously computed.

There is great interest in applying this spatial emittance correction to larger targets such as printed circuit boards, where several military programs are concerned with infrared mass screening of printed circuit boards for gross faults at the depot level. The approach used is to archive a standard thermal profile of a known acceptable board, and use this as a model against which to compare the profile of a powered unit under test. Variations in component surface characteristics within acceptably small ranges of variation, and conformal coatings introduce some degree of uncertainty to the comparison and the resulting differential image. The difficulty in developing a reliable emittance matrix lies in achieving tight control over the temperature and temperature uniformity while heating a target of this size and in controlling component surface and coating.

Table 1. Instrument Characteristics

	Manufacturer Model (s)	Characteristics
A. Spot Measuring		
1. Probes		
Dickson	IR500	32-500°F., LCD display
Exergen	Microscanner	10-550°F., one piece with bar graph, no numerical display
Horiba	IT330	32-500°F.,LCD display, emissivity control (e set)
Linear	C500, C600 series	0-600°F., C500 connects to a multimeter, C600 has LCD Box, e set, multiple models with various ranges
Testoterm	Pyroterm	50-700°F., LCD display, e set
2. Hand-held	(use 9V disposable batteries unless indicated)	
Capintec	Thermohunter HR	-50 to 900°F., e set
Everest	Industratherm	Various models from -30 to +1000°F., LCD display, analog output, aiming light, peak Sampler, differential available. rechargeable battery
Ircon	Ultimax series	Various models, -58 to 5432°F., thru-lens sighting, variable focus, reticle display
Land	Cyclops series	High and low temperature (to 5500°F.), small targets, variable focus, reticle display
	Compac 3	Low temperature, -50 to 950°F., thru-lens sighting, fix-focus reticle display
Linear	TherMonitor	TherMonitor- -20 to +2000°F., F.-C. switch, LCD display, e set, peak-hold.
	ThermoFlow	ThermoFlow reads in BTU/sq.ft./hr., differential scale
Mikron	Model 90 series	Various Models from -50 to +5432°F., thru-lens sighting, reticle display, variable focus
	Model 80 series	Various models from -20 to 3180°F.,analog & LCD displays, Options: aiming light, telescope, e set, various FOV's.
Pyrometer	InstaTherm	Various models from -30 to +1145°F, analog & LCD Displays, differential scale, audible seeker, analog output
Raytek	Raynger PM series	Various models from 0-1600°F., dual LCD display, hi-lo alarms RS-232/analog output, datalogger, max-min-mean, differential,
	Raynger II Plus	Various models from -20 to +5400°F. LCD displays, max-min-mean differential, thru-lens sighting; scope, 120:1 optics available

(continued)

Table 1. Instrument Characteristics (continued)

Manufacturer	Model (s)	Characteristics
A. Spot Measuring (continued)		
2. Hand-held (continued)		
Telatemp	Models 43&44	Various Models from 0 to 1000°F., Rechargeable Battery, e set, LED Display. laser aiming & scope available
Wahl	Heat Spy Series DHS	Various Models from -40 to +3100°F., analog, LED, LCD display e set, peak-hold, various FOV's including telescopic.
Williamson	600, Viewtemp, Truetemp	Viewtemp is 75-3000°F,LED inside reticle, e set, rechargeable battery; Truetemp is 2-color, 1500-4000°F., Model 600 has analog display, various Ranges from 75-3000°F.
3. On-line		
Barnes	RM2	Infrared microscope - spot size down to 0.0003".
Capintec	Hotshot, Redeye Ratioscope 1400,1500,1700	3 Models of 2-color from 300-6500°F., various other models from -60 to +4500°F.,spectral selection
E²Technology	Heat Switch 100 &300, Pulsar II Nova	Infrared Pulse Switches, 2 Models of on-line units, ranges from 32 to 3000°F.
Everest	2000,3000 series 4000 series	Ranges from -30 to +3000°F., spot size available down to 0.010" Multiplex up to 8 heads thru electronics
Ircon	Modline 4 series	Various models and accessories, 0-2500°F.,integrated, fix-focus, 2 wire transmitters, spectral selection
	Modline Plus and Mirage series	Various models, 2 piece, 0-6500°F.,thru-lens sighting, LCD display, spectral selection
	Maxline series	Various models, 2 piece, 0-6500°F.,thru-lens sighting, LCD display, spectral selection, plus control and output options
	Temprox switch and Series 1100	IR Pulse switches, fiber optic-coupled head available
Irtronics	Argosy, Citation Spartan, others	Various ranges from 30-4100°F., spectral selection, telephoto fiber optic-coupled heads available.
Land	Systems 1,2,& 3	120-4000°F., 2 color, spectral selection, telephoto lens option., modular, many accessories
Linear	TM1000 series	Modular sensors, ranges from 0-2732°F.,thru-lens sighting, spectral selection,linearized outputs,control options available.
	M series	Low cost modular sensors, many control options available

Table 1. Instrument Characteristics (continued)

	Manufacturer Model (s)	Characteristics
A. Spot Measuring (continued)		
3. On-line (continued)		
Mikron	M67/68S series	Modular, Ranges from 0-3000°F., spectral selection, fixed and variable focus, thru-lens sighting, many accessories
	M210/210S series	2 piece, 0-5400°F.,spectral selection, fixed and variable focus, thru-lens sighting, many accessories
	M500	Small, low cost, 2 piece, various models 0-500°F.
	M77/78	M77 is 2 color, M78 is fiber-optic coupled
Pyrometer	Optitherm II	Integrated head, various ranges, spectral selection (s.s.).
	Optitherm 87	2-piece, thru-lens sighting, telephoto lenses, s.s. var.rnges.
	Pyrolaser Laser Pyrometer	1100-2730°F., uses laser to measure reflectance, thru-lens sighting, rechargeable battery
Quantum Logic	Model 1300 Laser Pyrometer	1475-5500°F., uses laser to measure reflectance, thru-lens sighting, reticle display, disposable AA batteries(6), 0.9µ
Raytek	Thermalert IT series	Various models, 0-1000°F., 2 piece, small sensing head, e set
	Thermalert ET series	Various models, 0-3000°F., integrated sensing head, e set, processing options, s.s.
	Thermalert III series	Various models, 0-5400°F., 2 piece, LED display,e set, processing options, s.s.
	Thermalert IV series	Various models, 0-5400°F., 2 piece, dual LED display and set points, e set, processing options, s.s.
Vanzetti	Series TM1&TM2	Fiber optic coupled systems, 104-5000°F.,s.s. to 4.5um, many accessories; models without fiber optics available.
Watlow	Thermoducer	Various models, 32-932°F, small sensor, electronics
Williamson	Series 3000,4000 6000,7000,8000,9000	Various models including 2 color, fiber optic coupled, 75-4000°F., s.s., many accessories.
	Transtemp 1000 series	Various models, 0-4500°F, 2 wire fix focus transmitters
	Transtemp 590	0-100°F 2 wire fix focus transmitter
B. Line scanners		
Agema	Thermoprofile 5 series	Modular, thermoelectrically cooled, high resolution analog and digital outputs; operates with control system host computer
Pyrometer	ThermATrace	Uncooled, provides composite visual image and IR linescan of temperature; portable, rechargeable battery, SX70 photorecording

continued

Table 1. Instrument Characteristics (continued)

Manufacturer	Model (s)	Characteristics
C. Thermographic		
1. Thermal Viewers		
AGEMA	110	Thermoelectrically cooled, CRT display, thru-eyepiece recording, Polaroid or conventional film, rechargeable battery., 6°x12° FOV, -23 to 1100°F range.
Hughes	Probeye	Argon-cooled, LED Display, thru-eyepiece recording, Polaroid or conventional film, rechargeable battery, 7.5°x18° FOV, range to 1337°F.
2. Pyrovidicon Imagers		(Uncooled- operate at ambient temperatures)
I.S.I.	86, 91, 93, 94	Portable & 2 piece systems, FOV (lenses) from 9° to 60°, iris attenuators, profile & chopper options, 93 has environmental enclosure, 94 has built-in thermometer and diagnostics.
I.T.M.	202 & 203	Custom portable & 2 piece systems; many optional features
Xedar	XS410,XS412	Portable & 2 piece systems, 18° & 30° FOV, profile, chopping, synchronous chopper option, & image processing options available
3. Raster Scanners		(Liquid nitrogen cooled unless indicated)
AGEMA	870,880,450	Reflective Scanner based on SPRITE technology, 870 and 450 are TE-cooled. Rechargeable battery or line power, FOV (lenses) from 7° to 40°,3-5 or 8-12μ, filter wheel, TV scan rates isotherms, color, VCR, image processing, expandable software
Barnes	CompuTherm	Microimager, spot downto 0.0003", bench top unit,IBM AT/based features spatial & computation & integral image diagnostics, (storage, subtract, manipulate,etc.) interchangeable FOV's Scan speed 1,¼second, 3-5μ reflective scanner.
FLIR Systems	100	2 element high resolution usually airborne; refractive/reflective optics, 8-14μ, TV scan rates
Hughes IPD	7100,7300	TE-cooled,30 element HgCdTe reflective scanner, 20°Vx28°H FOV Image storage & comparison capability; computer interface, videorecording and expandable software;TV scan rates,rech. or line power.
	5000,3000 series	Argon-cooled 10 element InSb reflective scanner,rech. battery or line power, field or lab, expandable software
Hughes SS	ThermaScan	System for printed circuit card screening and diagnostics; includes high resolution 8-12μ scanner, power supplies, computer, holding and positioning fixtures, extensive diagnostic software.

continued

Table 1. Instrument Characteristics (continued)

C. Thermographic (continued)

3. Raster Scanners (continued)

Manufacturer	Model (s)	Characteristics
Inframetrics	522,522L,600 600L,610,	1 element reflective scanners, rechargeable battery or line power, FOV 14°Vx18°H with 4:1 zoom available, TV Scan Rate, 3-5 & 8-12μ, Features: Isotherms, color, VCR, image processing, expandable software
	IRAMS	System for printed circuit card screening, similar to Hughes ThermaScan
JEOL	(marketed by UTI)	High resolution reflective scanner, cart-portable, line powered FOV 20°Vx25°H, frame rate-1, 2 & 4/ second, X & Y profile, color, VCR, video processor, printer
	JTG 3110	InSb detector; 0.6, 1.3, 5.2 second/scan; 300 elements/line, 230 lines; line power; IEEE bus
	JTG 3210	HgCdTe detector; otherwise same as 3110
Mikron	6T62,63	High resolution, 3-5, 8-13μ, reflective scanner, line-powered with battery option, FOV 25°Vx30°H, Frame rate-1, ½,& ¼/second, color monitor, VCR, image processing and expandable software
UTI CCT 9000		Bench top unit aimed at production circuit board analysis, reflective scanner, FOV 30°x30°, 2-12μ, fully computerized with extensive analysis & storage capacity. RGB Color, Scan rate 1/second.

Table 2. Instrument Manufacturers

Company Name	Mailing Address	Telephone Number
AGEMA Corporation	550 Country Ave., Secaucus, NJ 07094	(201) 867-5390
Barnes Division, EDO Corp.	88 Long Hill Cross Rds.,Shelton, CT 06484	(203) 926-1777
Capintec Instruments Inc.	6 Arrow Rd., Ramsey, NJ 07466	(201) 825-9500
The Dickson Company	930 S. Westwood Drive, Addison, IL 60101	(312) 543-3747
E^2 Technology Corp.	1545 Morse Ave., Ventura CA 93003	(805) 644-9544
Everest Interscience Corp.	PO Box 345, Tustin, CA 92680	(714) 992-1461
Exergen Corporation	307 W. Central St., Natick, MA 01760	(508) 875-2387
FLIR Systems	11830 SW Kerr Pkwy, Lake Oswego, OR	(503) 245-0771
Hughes Industr. Products Div.	6155 El Camino Real, Carlsbad, CA 92008	(619) 438-9191
Hughes Support Systems	P.O. Box 9399, Long Beach, CA 90810	(213) 513-4786
Horiba	1021 Duryea Avenue, Irvine, CA 92714	(714) 250-4811
Image Technology Methods	103 Moody St., Waltham, MA 02154	(617) 894-1720
Inframetrics	16 Esquire Road, N. Billerica, MA 01862	(508) 670-5555
Ircon, Inc.	755 N. Linder Ave., Skokie, IL 60077	(312) 967-5151
Irtronics	59 Commerce Rd., Stamford, CT 06902	(203) 348-2671
I.S.I. Group, Inc.	9617 Acoma St. SE, Albuquerque, NM 87123	(505) 295-7646
JEOL Ltd. (USA) (see UTI)	235 Birchwood Ave., Cranford, NJ 07016	(201) 272-8820
Land Instruments, Inc.	Box 1623 Fox & Main, Tulleytown, PA 19007	(215) 943-7882
Linear Laboratories	2490 Charleston Rd, Mountain View, CA 94043	(415) 969-4999
Mikron Instrument Co., Inc.	PO Box 211, Ridgewood, NJ 07451	(201) 891-7330
Pyrometer Instrument Co.	234 Industrial Pkwy., Northvale, NJ 07647	(201) 768-2000
Quantum Logic Corp.	99 E. Kansas St., Hackensack, NJ 07601	(201) 342-0303
Raytek, Inc.	1201 Shaffer Rd., Santa Cruz, CA 95060	(408) 458-1110
Teletemp Corp.	PO Box 5160, Fullerton, CA 92635	(714) 879-2901
Testoterm, Inc.	PO Box 111509, Nashville, TN 37211	(615) 834-5082
UTI Instruments Co.	497 S. Hillview, Milpitas, CA 95053	(408) 738-3301

continued

Table 2. Instrument Manufacturers (continued)

Company Name	Mailing Address	Telephone Number
Vanzetti IR Systems, Inc.	111 Island St., Stoughton, MA 02072	(617) 828-4650
Wahl Instruments, Inc.	5750 Hannum Ave., Culver City, CA 90203	(213) 641-6931
Watlow Manufacturing	1 Richmond Square, Providence, RI	(401) 521-7410
Williamson Corp.	1152 Main St., Concord, MA 01742	(617) 369-9607
Xedar Corp.	2500 Central Ave., Boulder, CO 80301	(303) 447-1822

Table 3. Compilation of Typical Industrial Applications of Thermal Imaging Instruments

Typical Applications by Industry

Industry	Applications
Metals	Continuous casting, strip annealing, extrusion presses, rolling mills, induction heating, resistance heating, heat treating, electrolytic refining
Glass	Tank refractories, glass body temperatures, mold temperatures, bottle machines, float glass, tempering and annealing, fiberglass manufacturing
Cement	Kiln shell, refractory insulation, bridge delamination inspection
Textiles	Permanent press heat setting, dye setting, foam lamination, carpet backing
Plastics	Vacuum forming, extrusion, film process monitoring and control
Paper	Dryer drums, coating ink drying
Chemical and Petroleum	Furnace tube temperatures, pipe and vessel corrosion, mixing process monitoring and control
Food and Confectionery	Rotary Cooker temperatures, continuous infrared ovens, mixers, continuous baking ovens, freeze-dry processes
Asphalt Paving	Road stone dryer, mixing temperature, rolling temperature
Rubber	Hot rubber sheets-cooling and rolling, tire testing

Typical Applications by Discipline

Discipline	Applications
Design	Exhaust stacks, flue pipes, Heating units (ovens, boilers, furnaces) Buildings (offices, schools, hospitals, plants) Process pipes, vessels, lines: steam and water lines Kilns Cryogenic Storage Vessels Electrical and electronic circuits and microcircuits
Workmanship	Operational procedures Installation of refractory materials Installation of foam insulation materials Installation of fiberglass materials (roof insulation, etc.) Replacement of parts and other repairs Roof inspection for moisture saturation
Component Failure	Steam traps, underground steam lines Electrical lines and substations Electrical and electronic components and modules Insulation-foam, fiberglass and refractory Seals, low and high temperature Doors, ports, windows Cooling towers, heat exchangers Plumbing lines and systems Motors, pumps, ventilators, bearings