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Miniature High-Performance MNT/IOSPEC Infrared Diagnostic System for the Remote Monitoring of Astronaut Health

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ABSTRACT

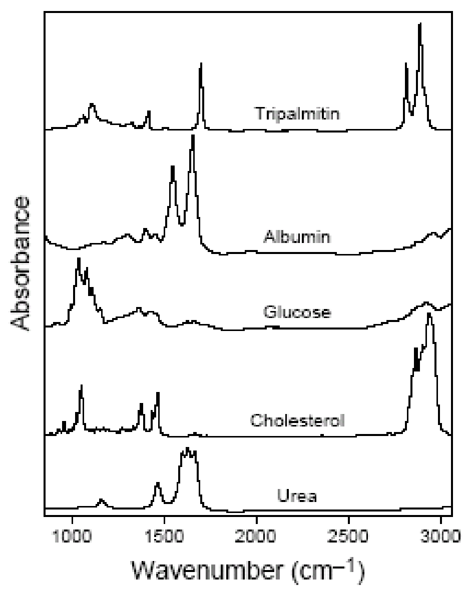
Manned space systems have many require-ments for the monitoring of vital life support systems including cabin air quality, quality of the recycled water supply, as well as direct monitoring of vital indicators of astronaut health, such as breath analysis and urine analysis. Infrared (IR) spectroscopy probes the charac-teristic vibrational and rotational modes of chemical bonds in molecules to provide information about both the chemical composition and the bonding configuration of a sample. The significant advantage of the IR spec-tral technique is that it can be used with minimal con-sumables to simultaneously detect a large variety of chemical and biochemical species with high chemical specificity, as shown in Fig. 1. To date, relatively large Fourier Transform (FT)-IR spectrometers employing variations of the Michelson interferometer have been successfully employed in space for various IR spectros-copy applications due to the attainable performance. However, FT-IR systems are mechanically complex, bulky (> 15 kg), and require considerable processing and recalibration.

This paper considers the use of advanced mi-cro-nano MEMS and integrated-optic technologies for optical processing and smart optical coding to extend the performance attainable for miniature IR spectrome-ters to facilitate a high-performance, miniaturized spec-tral measurement system that can be applied to various aerospace applications. This can provide the next-generation of compact, high-performance IR spectrome-ters with monolithically integrated optical systems for robust optical alignment with a module total mass under 2 kg to minimize the mass penalty for space applica-tions.

1. Technology Candidate

The proposed concept is based on MPB'S patent-pending Integrated Optical Spectrometer (IOSPEC^{TM}) technology for high performance miniature IR spectrometers [1,2]. Rather than relying upon disposable chemical reagents to promote color reactions that require significant operator intervention, IR-based analysis is founded upon the characteristic spectrum of IR absorption bands of the analyte itself [3]. This approach uses minimal consumables and relaxes operator expertise requirements.

Fig. 1: MIR absorption spectra for selected serum constituents. The spectra for urea, glucose, and albumin were acquired for aqueous solutions using an optical path length of 6 μm (the spectrum of water has been subtracted) [3].



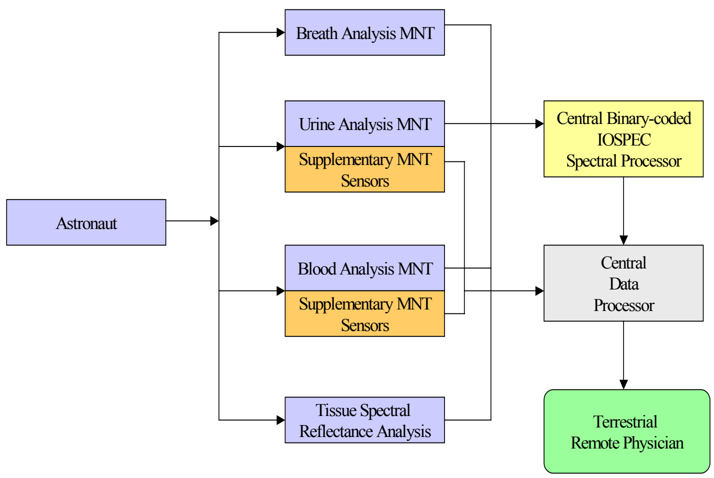
The proposed MNT pilot development would employ an advanced version of MPB's IOSPEC technology for miniature IR integrated spectrometers to form the central IR spectral processor that would enable a suite of comprehensive medical diagnostics in a compact package that would offer a substantial mass reduction and performance advantage over competitive technologies.

There are four areas in which the MNT IOSPEC system can be used to form a comprehensive suite of health diagnostic tools (see Fig. 2):

- breath analysis.
- urine/saliva analysis.
- blood analysis.
- tissue analysis.

The listed applications differ in the required sample retrieval and analysis chambers, as well as the background IR spectral libraries for the data analysis. However, they can share a common IR spectral processor, spectral library and the signal micro-processing. MNT can play a role in the miniaturization of the various subsystems using microfluidics and hollow waveguides.

Fig. 2: Integrated MNT laboratory for astronaut health monitoring based on binary-coded IOSPEC spectral integrated-optic microprocessor.



Additional MNT sensors can be linked to the specimen collection system to supplement the IR spectral measurements, such as pH measurements, heart-beat, blood pressure and body temperature, etc. This can provide a relatively comprehensive health analysis laboratory. The resulting data can be downlinked to a qualified terrestrial physician for remote diagnosis. The proposed MNT development can also address the needs of the far larger terrestrial health market by facilitating rapid diagnostics at the physician level prior to costly laboratory analysis. By integrating data from several different measurements, a more accurate diagnostic should be feasible.

It is proposed that the pilot concept development focus on the non-obtrusive analysis of urine and saliva samples, as shown schematically in Fig. 3. This can provide diagnostics for a wide range of medical disorders [3] and requires minimal operator sampling skills and training. A sample of the liquid would be injected into a microfluidic sample chamber. This would be integrated with a micro IR illumination source and additional integrated-optic/MOS (Metal-Oxide-Semiconductor) sensors for extracting critical parameters such as the PH level of the fluid. Direct analysis of the molecular composition of the fluid would be accomplished using the miniature MN/IOSPEC IR spectral processor. Differential spectroscopy using a reference fluid sample can be used to extend the accuracy of the system to trace impurities. The data can then be processed and correlated using a dedicated DAQ/microprocessor board such as the 16 bit, low power, 4” by 5,” 16 bit complete dual processor system that MPBC is currently developing for its Fiber Sensor Demonstrator payload for ESA’s Proba-2.

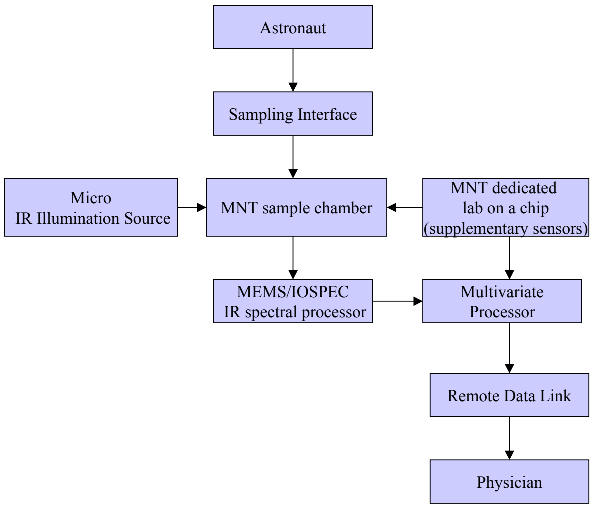


Fig. 3: Detail of MNT/IOSPEC diagnostic system.

MPBT has advanced its IOSPEC technology for miniature integrated IR spectrometers to provide high performance comparable to large bench-top FT-IR systems but in a very compact and ruggedized footprint [4]. IOSPEC employs a broad-band IR slab-waveguide structure to integrate an input IR fiber or slit, a concave reflection grating, and a linear detector array at the optical output plane, in a compact, monolithic structure. The optical signal is guided within the slab waveguide onto a master blazed grating structure that also serves as a concave reflector. The precision master grating, formed using batch microfabrication techniques, provides diffraction efficiencies approaching theoretical limits (> 85% peak diffraction efficiency) with low background signal scattering (<0.05%). Additional integrated optics are used to linearize the output focal plane, providing a 4000 nm broad-band linear focal plane that is about 20 mm wide, enabling relatively high spectral resolution.

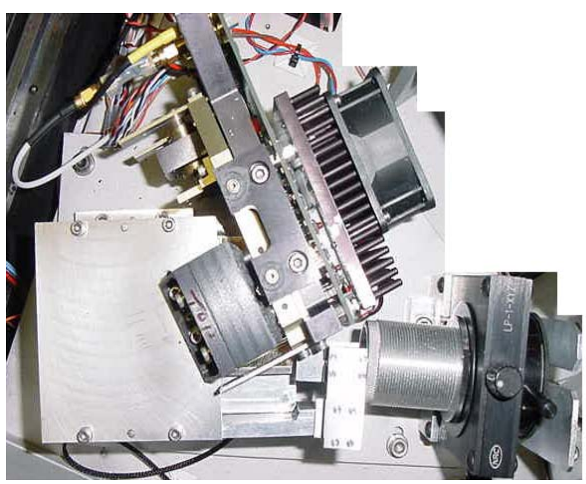


Fig. 4: Photograph of current IOSPEC module weighing under 2 kg including input optics and cooled detector array.

The current 1.2 to 5 µm IOSPEC integrated optical spectrometer prototype has been packaged by MPBC in a compact module, as shown in Fig. 4, that is only about 20 x 20 x 15 cm in size and weighs under 2 kg. The spectrometer is optimized to operate with small light sources such as tungsten lamps.

IOSPEC employs an electronically-scanned detector array that provides relatively high spectral scan rates, exceeding several hundred scans per second, to facilitate a high "real time" sample throughput. The elimination of moving components and integration of the optical system provides more reliable long-term performance in non-ideal environments. Even with cooling and nominal temperature stabilization, infrared detector arrays operating at longer optical wavelengths, such as PbSe, exhibit some unwanted signal drift and instability that can be comparable in magnitude to weaker optical signals. The attainable detectivity of an infrared detector array can be significantly less than that indicated by the theoretical NEP rating of individual pixels due to the multiplexing nonidealities and nonrandom detector system and light source variations.

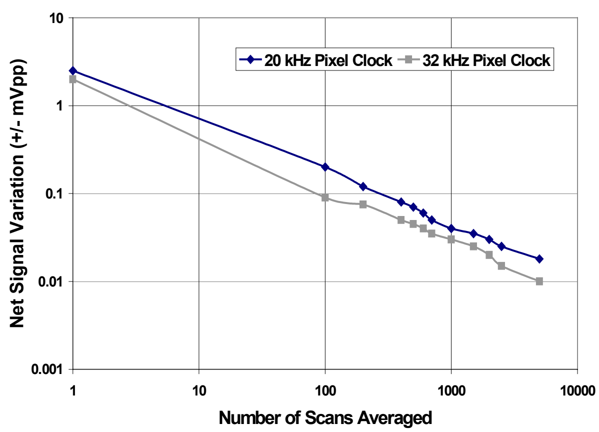


Fig. 5: Variation of typical noise for 256 pixel multiplexed PbS array at 260K with the number of scans in active smart average.

Using the traditional signal averaging techniques, the ultimate signal detectivity achievable rapidly saturates due to the increasing contribution of systematic variations in the detector signal, significantly limiting the attainable SNR. Proprietary, patent-pending active optical signal processing and averaging algorithms have been developed by MPB that facilitate a significant increase in the attainable SNR for multiplexed linear detector arrays. With the active smart averaging, as shown in Fig. 5, no saturation in noise reduction was observed, providing the potential of two to three orders of magnitude improvement in the attainable SNR relative to traditional signal processing techniques.

MPBC and the Canadian Space Agency [5] are currently developing proprietary algorithms to binary code the optical input to diffractive spectrometers such as IOSPEC to further improve the attainable SNR and spectral resolution. The traditional single input slit is replaced by an N_s array ($N_s \geq 8$) of programmable slits using MPBs VOn thin-film optical switching technology. This increases the effective input aperture by a factor of $N_s/2$, resulting in an unrestricted input aperture for diffractive spectrometers. The optical decoding facilitates a further theoretical gain in SNR by a factor of $N_s^{0..5}/2$ due to input data multiplexing and redundancy. The main requirement is that the binary transformation matrix employed for the optical coding have an inverse. The actual processing combines MPBC's smart averaging algorithms with the binary coding to provide a further order-of magnitude improvement in the SNR than is possible using traditional Hadamard transform techniques alone [6,7,8].

Table 1: Summary of achieved SNR gain using 16 slit binary code.

Case	Peak to peak transmittance ripple.	Net SNR Gain
	(near pixel 200)	
Smart processing on 16 sequential scans	+/- 0.01	1
Demultiplexed single scan from 16 slit multiplexed data.	< +/- 0.004	2.5
Using 16 scan redundant demultiplexed data.	< +/- 0.002	> 5

Using a 16 slit code, corresponding to a 16 x 16 invertible binary code, a net gain of 2.5 was achieved relative to using a single slit measurement for the same processing time. However, after decoding the multiplexed data, one is actually left with 16 estimates of the spectrum. By processing this redundant data, a further gain in SNR can be achieved, exceeding a factor of 5 for 16 slits, as summarized in Table 1. Since the typical SNR of a diffractive spectrometer is proportional to the square root of the input slit width, given similar spectral resolutions, this corresponds to a factor of 25 in the spectrometer size reduction. Depending on the number of input slits and the characteristics of the illumination source, still further gains in SNR or reductions in the measurement time and/or source intensity are feasible.

There are six main benefits to the binary-coded IOSPEC spectrometer relative to the single slit spectrometer:

1. Increase in effective input luminosity by a factor of $N_s/2$
2. Each detector pixel sees up to N_s wavelengths simultaneously.
3. $N_s^2/4$ sets of redundant data after each sequence of measurements to enable further signal averaging.
4. Linear spectral shift due to each slit facilitates improvement in spectral resolution.
5. Redundant data can be used to eliminate effects of dead pixels in linear array.
6. Binary coding enables a simple inverse transform.

One potential solution to the realization of a programmable array of optical shutters is the use of smart coatings that exhibit a metal-insulator transition [9,10,11]. This has significant benefits in terms of the mechanical simplicity, reliability, achievable packing density, and the achievable optical performance. Fig. 6 shows the FT-IR transmittance spectrum of a 250 nm thick VO_2 coating deposited onto polished crystalline silicon (c-Si) as measured relative to uncoated c-Si above and below the nominal transition temperature of about 68^{o}C.

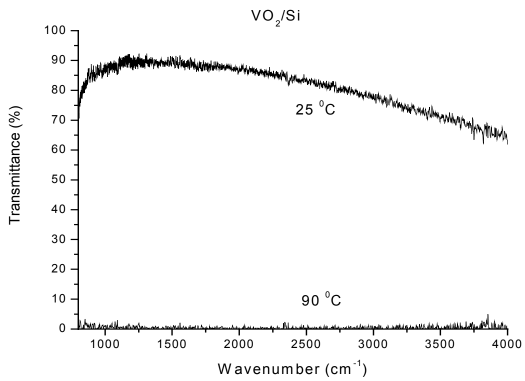


Fig. 6: FT-IR optical transmittance of MPB/INRS VO_2 on Si in the insulating (29^{o}C) and metallic (95^{o}C) states.

The metal-insulator transition is induced once a critical free electron density is established; either through thermal carrier generation or by electric-field induced band bending. In the semiconducting state below 68^{o}C, the VO_2 exhibits relatively high transmittance extending to beyond 12 μm. In the metallic state at higher temperatures, the transmittance decreases to below 0.2%, depending on the film thickness. In the NIR, usable optical switching can be provided by the VO_2 to about 1.3 μm. The thermal switching point can be regulated by doping with impurities, similar to semiconductors such as crystalline Si. The optical switching can also be induced electrostatically by field effect, similar to the operation of a MOS field-effect transistor.

Work is currently underway to develop a 32 element shutter array that can be integrated at the input of the current 1.2 to 5 μm IOSPEC spectrometer based on MPB's VO2 thin-film smart material broad-band optical switch [5]. The physical characteristics of the shutter array (i.e. slit spacing, slit width) are tailored to the output dispersion characteristics of the spectrometer. In this respect, the use of the integrated IOSPEC spectrometer with a very precisely defined output focal plan and linear spectral dispersion characteristic is very advantageous for the successful implementation of the coding technology.

By using optical coding at the spectrometer input, the effective input aperture and luminosity, for a given spectral resolution, is increased by a factor of $N_s/2$. This increases the signal measured at each detector pixel due to the multiplexing of N_s wavelengths. The second benefit is the averaging of the resulting N_s redundant information after demultiplexing to provide an additional reduction in noise.

In the application of the binary-coded IOSPEC spectral processor for astronaut health monitoring and environmental control, one must consider the entire system requirements (sample chamber, illumination system, supplemental biochemical sensors) and the potential benefits of applying micro-nano technologies to reduce the net system size, increase critical system redundancy and improve the system reliability and achievable performance.

2. Technology Application Areas

The detection and identification of molecular structures is a vital component of space exploration for planetary atmospheric studies, planetary geology, and astrobiology [12,13,14]. It is also an important requirement for manned missions in space for the monitoring of vital life-support systems such as water and air recirculation systems [15,16,17].

Manned space systems have many requirements for the monitoring of vital life support systems that can be accomplished with minimal consumables using IR spectroscopy, including

1. Monitoring of the spacecraft recirculating air supply.
2. Monitoring of the spacecraft recirculating water supply.
3. Astronaut blood, urine and tissue NIR/MIR analysis (portable health analysis unit).
4. Trace biochemical hazard detection.

However, the current proposed systems [18] based on FT-IR instrumentation are quite massive (> 30 kg), requiring two Shuttle middeck lockers, mechanically complex, requiring calibration and realignment, and costly.

Examples of additional applications for the miniature optically-coded spectrometer include:

- Gas monitoring (examples) - CO, CO_2, CH_4, NO, N_2O, SO_2, PH_3, AsH_3 - pollution monitoring - greenhouse gases
- atmospheric aerosols and dust that can affect weather patterns and precipitation
- "in-situ" science experiments in space - evaluation of materials, monitoring of space experiments such as plant growth
- identification of minerals and planetary resources (i.e. rock type, ore content) geology
- analysis of ice, water, bio-indicators and microbes (astrobiology)

3. Benefits of Proposed Technology

1. System operation doesn't require expert knowledge or extensive training.
2. Measurement system uses minimal consumables (basically illumination lamp) providing considerable benefits for use in remote locations.
3. Using MNT to miniaturize the system while maintaining and/or improving achievable performance can provide a substantial savings in mass and volume for the instrumentation.
4. Mass savings can be used to facilitate redundant systems for critical aerospace applications.
5. Minimal moving parts for robust system alignment and high long-term reliability.
6. Proposed technology can be applied, with minimal customization, to address a broad range of aerospace and terrestrial opportunities.
7. By facilitating rapid diagnostics at the physician level prior to costly laboratory analysis.
8. By integrating data from several different measurements, a more accurate Medical diagnostic should be feasible.

4. Estimated Potential market

The aerospace market segment that can benefit from the proposed micro-nano technology development includes both unmanned space exploration (ice/liquid analysis, bioindicator detection) and science, Earth observation missions (atmospheric studies, remote sensing), and critical monitoring of the environmental systems for manned missions (space shuttle, space station), as well as astronaut heath.

As a first iteration for the MNT concept development, it would be best to focus on a single analysis application. The two most unobtrusive are breath analysis or urine analysis.

The proposed MNT can also address the far broader terrestrial clinical markets and the requirements to enable terrestrial remote medicine in areas where medical laboratories are not readily available, facilitating rapid diagnostics at the physician level prior to costly and time-consuming laboratory analysis. By integrating data from several different measurements (breath, urine, etc), a more accurate diagnostic should be feasible.

The global market for medical equipment exceeds $260E9 U.S. with about 40% of this spent on non-disposable equipment. The market segments vary from large central hospitals, to local clinics, to the point-of-care physician. The market size increases quantity wise, but the sustainable equipment cost must be reduced, as one moves down the chain to the physician level. Remote telemedicine for patient care is gaining attention but must prove its cost benefit and value to the patient.

Obviously, the largest commercial market would be to have the instrument as a standard first-line diagnostic tool of the family practitioner. This market segment requires clinically-proven diagnostic accuracy, high reliability, non-expert operation and affordable costing. The proposed diagnostics are generic to most check ups and are therefore performed with a high frequency. If the cost of the proposed MNT/IOSPEC diagnostic systems could be reduced sufficiently, then the systems could even be considered for remote “at home” patient care. Given the per day cost of hospital beds, a tremendous cost savings can be offered to government and private medical plans while improving patient comfort. For remote health care, depending on pricing, equipment could be temporarily leased to the patient, or, for long-term monitoring, purchased by the patient assuming that the cost meets patient affordability.

Additional terrestrial applications include monitoring of building air systems and the quality and safety of township water supplies. Water monitoring is currently largely performed by periodic sampling and subsequent analysis in a laboratory. This requires considerable costly technician intervention and results in significant time delays and a relatively low sampling frequency. As a result, there have been several incidents of large-scale heath problems that resulted in subsequent costly health care requirements. With the gradual decline in water quality due to industrial activities and finite water reserves, as well as the threat of terrorist activities; the online regular monitoring of municipal water is a market that can be evolved. The diagnostic equipment could be remotely linked to regional laboratories for evaluation and appropriate actions. Cost savings can be accrued by reducing technician intervention while simultaneously improving the monitoring standards to benefit the general population.

The following table provides a very preliminary summary of some of the potential markets and market sizes. The net potential market exceeds $1E9 US. The space sector can sustain a higher unit cost due to the emphasis on performance in the space environment, but requires more costly rad-hard electronic components and extensive environmental testing. However, given that launch costs are of the order $50K US per kg, cost savings due to mass reduction using MNT/IOSPEC can exceed the cost of the instrument, relative to competitive technologies.

Table 2: ROM estimate of potential market for proposed MNT/IOSPEC development.

Market	**Estimated Unit Costing**	**Potential Units**	**Potential Market Value (U.S. $)**
Manned Space Systems	$250K+	10 to 50	1E7+
Remote Health Care – Emerging Market	$10K to 50K	100 to 10K+	2E6 to 5E7+
Clinical Diagnostics	$50K t0 $100K	1K to 10K+	5E7 to 1E8+
Physician point-of-care	<$30K	10K+	2E8+
Water Supply Safety/Quality	<30K	1K to 10K+	2E7 to 2E8+
Building Air Quality (govn. offices, public buildings, major businesses)	<30K	1K to 10K+	2E7 to 2E8+

5. TECHNOLOGY READINESS LEVEL (TRL)

Several technologies are inherent in the proposed MNT/IOSPEC concept for prototype development, with varying degrees of maturity as discussed in Appendix A.

6. Status of Competing Technologies

Current technologies for trace chemical detection include ion mass spectrometry [15], fluorescence spectroscopy [16], dedicated chemical sensors, and large-scale FT-IR infrared spectrometers [13,17].

Ion mass spectroscopy entails vaporizing a sample and measuring the corresponding mass of fragments in the vaporized sample using time-of-flight techniques. This is a destructive technique that can contaminate the measurement system. Additional time is required after a measurement to purge the sensor system prior to a subsequent measurement. The data output consists of the partial pressures of the vaporized sample fragments as a function of their total mass in AMU, up to about 300 mass units. Therefore, the data is not chemically specific. Different chemical compounds can exhibit similar masses, resulting in a relatively high rate of false alarms. Moreover, fragmentation of the sample and the resulting species that are evaporated is highly sample dependent, resulting in significant variations in mass spectra for similar trace constituents. Vapour samples are much easier to measure than solid or liquid samples. Bacteria and other biohazards can constitute large hydrocarbon molecules with mass >> 300 AMU and are therefore difficult to identify using this technique, since fragments can be nonspecific.

Fluorescence spectroscopy employs bacteria-specific tagged antibodies. The antibodies are prepared with a special additional molecular termination that fluoresces under excitation by suitable illumination, usually in the UV range. In this methodology, a portion of the sample under investigation is reacted with the tagged antibodies. The sample is then excited using suitable illumination, typically in the visible spectral range. If any tagged antibodies reacted with the specimen, then a fluorescence emission band can be observed using a VIS spectrometer. Each biohazard requires a specific tagged antibody. Usually a multi-chamber petri dish is employed, each chamber containing a different tagged antibody covering the range of anticipated biohazards. These analysis chambers typically require refrigerated storage and have a finite lifetime. They are disposed of after each test. The technique can detect bacteria levels down to 1000's level. However, sample preparation is relatively complex, time consuming and requires some expertise.

Most molecules that comprise solid, liquid or gaseous samples have characteristic vibrational modes associated with their chemical bonds that can interact with photons, resulting in optical absorption bands, mainly in the infrared spectral range, that provide a specific signature of the molecular structure (see Fig. 6). The optical absorption characteristics are indicative not only of the chemical bond but also of the actual bonding configuration (i.e. $X\text{-}Y_n$) and local chemical environment. Infrared spectroscopy, therefore, can provide quantitative information regarding both the chemical composition and chemical-bonding configuration of the elements comprising a sample. Infrared spectroscopy can therefore provide high specificity for the identification of a wide range of unknown substances, including pollutants and biochemical hazards, in vapor, liquid or solid form. The significant advantage of the IR spectral technique is that it can be used with minimal consumables to simultaneously detect a large variety of chemical and biochemical species with high chemical specificity.

To date, relatively large FT-IR spectrometers employing variations of the Michelson interferometer have been employed for IR spectroscopy applications due to the attainable performance. A schematic of a typical FT-IR system previously employed in space is shown in Fig. 7. FT-IR systems have two principle advantages over dispersive and filter instruments:

(1) A multiplex SNR advantage since the detector views all the wavelengths (within the sensor passband) simultaneously during the measurement to increase the effective integration time; and

(2) Enhanced light gathering capability since the aperture size (slit width or height) is not as severely limited as traditional dispersive instruments.

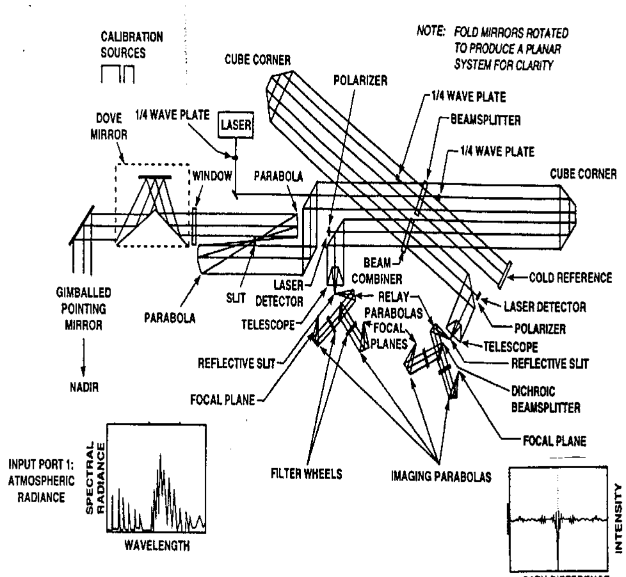


Fig. 7: Schematic of typical FT-IR system used in space (after [14]).

However, FT-IR systems also have a number of shortcomings. One major drawback of a FT-IR spectrometer is its mechanical complexity, as shown in Fig. 7, and the resultant high cost and limited mechanical reliability. The optical interferometer entails precision alignment and translation of several mirrors or cornercube reflectors over relatively large distances of up to +/- 25 cm for higher spectral resolution. This generally requires additional temperature control and vibration stabilization that adds to the mass and complexity of the overall system. The large size and mass (20-30 kg) of typical FT-IR instruments requires relatively expensive platforms for space-based systems.

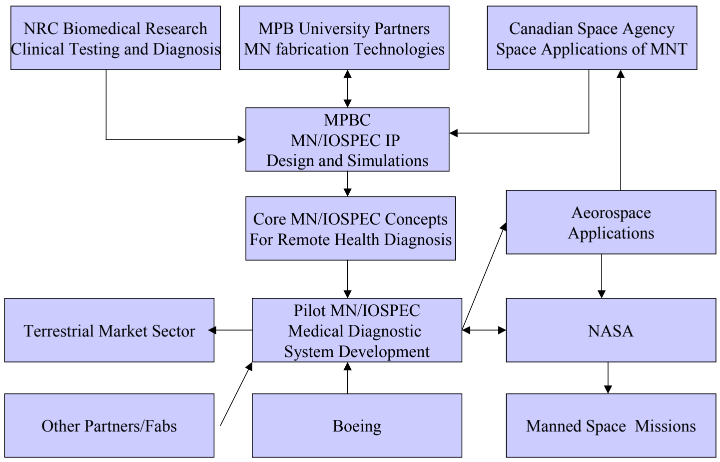
7. International Collaborations

The project will consider potential collaborations with Boeing, NASA and other interested international entities involved in the relevant application sectors.

8. Implementation of Pilot Project

The development of the MNT/IOSPEC prototype system will require the assembly of a multidisciplinary team with expertise both in the related medical fields as well as in MNT, MEMS and spectroscopy. From this vantage, MPB is excellently positioned due to its established contacts with various medical research institutes in Canada and the U.S.A. as part of its market development for MPB’s Freedom 6 handcontroller for remote medicine and telesurgery.

Table 3: Schematic of Potential Teaming for Project:



The pilot MNT design is based on a top-down specification of the system requirements and design. This is followed by a bottom-up development of the critical MNT subsystems.

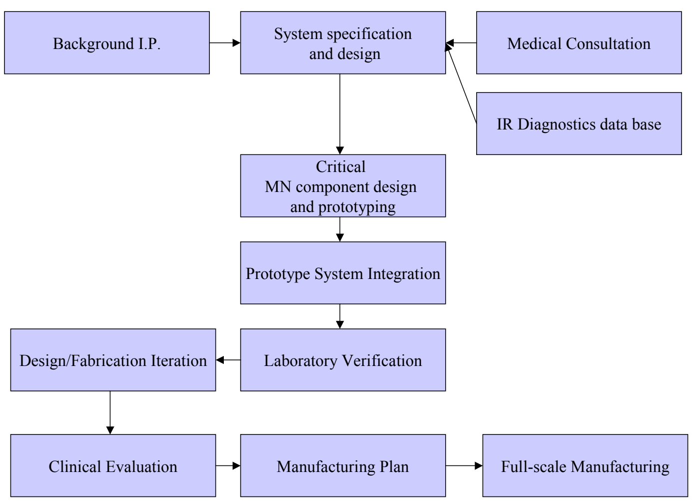


Table 4: Flow Chart of Project Methodology.

The project's new foreground intellectual property will be managed via the provisions of the various subcontracts and NDA's. Typically the originators of the I.P. are the owners with the financiers having the first right to license the I.P. for the product commercialization. The background I.P. is owned by the individual originators (contributors).

The development of some of the background MN technologies by MPBC that are associated with the proposed pilot project is currently being assisted through several contracts with various Canadian government agencies. The proposed pilot MNT project will require the establishment of sufficient funding to enable its progression. The largest potential beneficiary is NASA in the space sector. For the terrestrial market segment, various companies in the medical instrumentation or environmental monitoring sectors could be approached.

9. Recommendations:

- Set up preliminary project teaming.
- Detail concept MNT/IOSPEC instrument and its predicted performance.
- Specify required micro-nano technology development.
- Prepare instrument development plan.
- Identify potential sources of funding for pilot scale technology development (NASA, medical sector).
- Validate system performance through laboratory and clinical validation.
- Prepare commercialization plan for large-scale production.

10. Conclusions

The IOSPEC technology using proprietary MEMS/smart-material signal processing has extended the state-of-the-art for high accuracy infrared transmittance measurements by miniature spectrometers with a signal to noise exceeding 250,000 using cooled PbS detector pixels for the 1 to 3.5 µm range and a peak SNR exceeding about 50,000 using PbSe detector pixels. Total sample measurement times are typically under 60 sec. This has provided a measured resolution of the sample optical absorbance of better than +/- 0.00015 abs. units. These results were obtained using a 20 W lamp.

The integration of the IOSPEC IR spectrometer technology with advanced optical coding techniques and MEMS miniaturization technologies can provide a further order-of-magnitude improvement in the attainable performance for the next-generation IR spectrometers, while substantially minimizing the instrument mass, size and power requirements relative to traditional FT-IR. This can enable a level of science on smaller space platforms that approaches that of a terrestrial laboratory, enabling the accommodation of additional probes and specimen collection systems.

Direct detectivity of trace impurities in a matrix down to the low ppm level is feasible without sample concentration. With the addition of input optical signal coding using a programmable input shutter array fabricated using thin-film electrochromic materials, a further improvement in the SNR of a factor of 10 is feasible. This can be employed to extend the detectivity to ppb levels.

The proposed high-performance IR spectral processor can be the basis of various monitoring instrumentation for medical diagnostics, environmental monitoring, biohazard detection and space science. The pilot MNT/IOSPEC development would focus on a compact system for fluid analysis (urine/saliva) that would enable the remote/non-expert diagnosis of a wide array of diseases and medical problems. This could also be adapted to the monitoring of water treatment plants and various other chemical processes (food and beverage industries, dairy industry, homeland security, etc.).

In summation, the proposed MNT/IOSPEC miniaturized diagnostic system for remote health management can offer a comprehensive set of “real time” health diagnostics based on clinically proven use of IR spectroscopy to provide a broad, comprehensive snapshot of the health of an astronaut, enabling accurate remote diagnostics should any remedial action be required. The use of MNT and smart signal processing offers miniaturization with high performance. The attainable miniaturization facilitates sensor redundancy for greater measurement reliability in space. By minimizing and/or eliminating the need for consumables for testing, significant operational convenience is provided relative to standard laboratory test techniques based on chemical reactions of dedicated reagents. Moreover, the influence of operator error is minimized.

Acknowledgments

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