Good Vibrations Engineering Ltd.
12585 Weston Road
King City, Ontario
L7B 1K4
Phone: 905-833-0417
url: www.goodvibrationsengineering.com

Development of Space Robotic Force Moment Sensor

Date: June 02, 2017
by: Sherry Draisey

Executive Summary

A force moment sensor (FMS) informs a robot arm how hard it is pushing/pulling/twisting. When present, a FMS is positioned between the end effector (hand) and wrist. Only a small portion of robots are equipped with FMS. The terrestrial demands of FMS differ significantly to those for space. The development of an operationally suitable space robotic force moment sensor (FMS) has been eluding the space community for 30 years. Canadarm (shuttle arm) did not have a FMS. Canadarm2 and Dextre have FMS, but reliability is problematic for operations lasting more than ½ hour.

A FMS has applications in both human and autonomous space operations.

The space environment, and associated operational demand make FMS development a difficult problem. Then there are also ‘management issues’. The cost and schedule for FMS development exceeds what engineering program managers, as a single systems supplier are willing or able to invest. And then the other ‘management issue’ is the apparent simplicity of the problem.

A space FMS development demands specialization and long term commitment. It can be developed as a standalone product, to be sold to a variety of space systems developers, or kept exclusive to a single customer. As a ‘new product’, expected sales are expected to be nonexistent during the multi-year development phase. Our sequence of product development is addressing that. Marketing has begun with a simulator available for free, on-line. The simulation allows for insertion into a robotic control test bed.

Space robots such as the Canadarms receive attention when they’re in a camera equipped space arena. They move and perform counterintuitive tasks. The ability of the robotic control systems to perform constrained motion tasks is being inhibited by the lack of a space robotic FMS.
As a product, FMS represents a highly concentrated niche, for a long term product to both the human space flight and the on-orbit servicing market. It has been noted by one robotics ‘guru’ that space robotic FMS capability is a distinguishing feature. “Anyone can build a robot now, but ...”

The complexity of our FMS solution guarantees that production will remain with the expertise. The need for a complex solution has been validated by the number of international failures to demonstrate an adequately functioning space robotic FMS.

The initial development costs of the FMS are substantial, for limited annual sales. In the past 3 years, we have managed to make remarkable progress in reducing risk, at fairly modest cost. Technical ‘show stopper’ issues have been eliminated.

The market is limitless in duration. We have secured our approach with US patent, granted in 2016. By combining advanced marketing with simulator development, we have reduced risk and conceived a means of partially funding both technical and market development with near term sales. The 2nd version simulator (which incorporates error model of thermal influence) has been released (www.goodvibrationsengineering.com/FMS_SIM.html) .

1.0. Good Vibrations Engineering Ltd. (GVE)

12585 Weston Road
King City, Ontario
L7B 1K4

www.goodvibrationsengineering.com

Contact: Sherry Draisey
phone: 905-833-0417
email: sherry@gve.on.ca

1.1 Profile

Good Vibrations Engineering Ltd. is a privately held, Canadian company.
Sherry Draisey is owner and operator. The other staff members: Noah Mullins and Mayes Mullins.

1.2 R&D

The R&D initiative is for continuing development of a Space Robotic Force Moment Sensor. It is the continuation of development of a sensor concept, originally patented by Sherry Draisey/SPAR Aerospace in 1992. A 2nd US patent was granted in 2016.

During the 90's we received IRAP funding to build a 3 degree of freedom configuration, and some additional funding from the European Space agency to partially test it. The originally filed patent has now expired, but substantial new IP has been developed. A provisional patent was filed in 2014, just in advance of a presentation to Goddard Human Space Flight group. It was the NASA/GSF opportunity that linked to JPL's interest for Mars2020 rover drill. The opportunity to plant a concept in the minds of 20 or so space robotics researchers is a powerful, though very long term market advantage. At the time of presentation, Goddard Human Space Flight people were not interested in issue of constrained motion, but that will come. That 2nd patent was awarded in 2016.

There are several advancements since our 1st FMS patent. All focussed around the utilization of structural non-linearities which allow for the load transduction on the basis of frequency shift. The concept is summarized in a technical paper on our web site: www.goodvibrationsengineering.com/cctomm.pdf , though it does not reflect the more recent developments.

We began work on the 6 dof design, March 1, 2009. With funding to support hardware development, we expected a 4 year development cycle. There has been no external funding since 2009, except for small SRED payments from the Canadian Revenue Agency. In the absence of funding , we have developed, designed, analyzed, manufactured and begun testing a 250 ft-lb version. In parallel, we have developed the first two versions of our on-line simulator.

In the past year, we have built and partially assembled the 6 dof prototype. We have performed testing to the level of assembling (which is effectively the no-load, linear structure). That testing has eliminated several concerns. The ability to adequately excite all 6 dof forces, with a simple piezoceramic poling configuration had been a key concern that has been eliminated. The torsion mode had been of some concern, but it has proved to be easy to excite. We have identified all modes below 3300 Hz (Nyquist limited with the low cost equipment we are using). There are multiple modes for 5 dof's. The more modes for each force degree of freedom, the better the performance. The potential for the 6^{th} multiple mode dof exists in a higher frequency regime. We have been experimenting with getting adequate signal above our Nyquist limitation to further improve performance.

Our next steps are to complete assembly of the structure to quantify the non-linear frequency shifts which result from limited loading. High magnitude loading is where higher costs will occur, so we will proceed with low loading levels, until we obtain significant funding. After the low loading results are assessed, we will update the on-line software simulation to reflect our test data.

The testing results to date are quite consistent with FE results – not perfect, but reasonably close. Thus the FE has helped in initial predictions, but it is also helping us to identify means of exciting modes and means of identifying signature for various degrees of freedom.

1.3 Need for External Investment

We have managed to split off the high cost work on this sensor to later stage development. Some of that has been done by using low cost, low quality accelerometers with in-house s/w to compensate for lower quality instrumentation. But schedule itself has allowed us to perform low cost, high risk work at earlier stage.

The most expensive work will be to perform application of high load levels to the FMS. For reasons of safety, this task would best be performed robotically, within a specialized test cell. That work will be delayed until we have secured external investment.

There are several years worth of in-house work we can continue to perform, prior to the need to address high load levels. This in-house work will allow for upgrade to the FMS matlab simulator. Eventually, that simulator will completely reflect the characteristics of the FMS.

We no longer target the Canadian Space Agency as a potential customer. It is not clear whether a lead in space robotics can be maintained in Canada – but if it is, it will likely be through MDA. And we maintain visibility with them. Some of their recent management changes make us optimistic.

There commercial sector, in particular the on-orbit servicing sector, both for satellite repair and refurbishment will become a significant customer. The asteroid mining sector may also become a significant sector for, though that will depend on the approach they take to mineral extraction.

Had NASA continued with ARM (Asteroid Retrieval Mission), we were fairly confident they would find a way to get our sensor (for constrained motion tasks – ie 2 armed robots) included, but ARM has been cancelled. One of the potential human space flight replacements being mentioned in a cis-lunar station, complete with a sort of knock-off SSRMS. Our FMS would an obvious replacement for the existing FMS pair. The issue of latency and drift become much more significant as space stations become farther away from Earth.

A space robotic FMS represents a stable, long term product to the space sectors - civilian and defence. The FMS is a subsystem with applications in a variety of space robotic operations, with long term sales potential. The simple interface between our FMS and the systems it will be needed in (both the physical and computer interface) make it a good candidate for overcoming ITAR limitations.

Our costs of R&D and associated capital costs are substantial. One of our other products has begun to sell, and beginning to generate revenue that will allow us to slowly ramp up FMS development. But the only way we can accelerate that development time (to below 4 years) is to find an external funding source.

The nature of the FMS subsystem is such that no single systems supplier has the need to support the development of the force moment sensor. That could change, as the industry grows, and there is competition between space robotic suppliers.

Our potential market has grown significantly over the past 3 years. We anticipate long term annual sales of the device to be about four times our initial development costs.

A Canadian company clearly has the initial advantage in selling such a device - because of branding provided by the Canadarms. We are among a declining number of engineers who have design experience in that arena.

Our most prohibitive cost is the test rig hardware. But we are doing enough limited testing, to generate a simulation upgrade, based on modal testing results only, at a fairly modest cost. The initial product that controls engineers need is a simulation of the FMS device - to include in their test beds. That is cheaper for us to produce, than fully tested FMS hardware.

1.4 GVE Vision?

Does GVE have vision? Talk to Sherry privately, and she can give you proof.

2.0 Statement of Work

2.1 Overview of the Work

The goal of the work is the development of a pre commercial unit space robotic force moment sensor - both the hardware and software simulations of the unit. The approach to the work is parallel progress, alternating between analytical and experimentally driven development. This will allow for the demonstration of resolution capability for all 6 degrees of freedom force. The simulation product will provide customers with a low cost means of evaluating our FMS subsystem, within their system, at an early stage of their project (possibly even at their proposal stage).

2.2 Description of Major Activities and Expected Outcome

Table 2-1 presents the performance goals that the precommercial unit is to be designed to meet (and simulation shows we do meet them). Figure 2-1 provides the work breakdown structure for the plan to achieve these goals. The project schedule of section 2.3 is based on the work breakdown structure. The tasks of the WBS are defined based on the WBS. Some of tasks from WBS 110 and WBS 150 have been completed, and tasks for WBS 120 have all been completed.

Performance Characteristic	Max	Min
Measureable Force	400 N	2 N
Measureable Moment	350 Nm	1.5 N
Allowable Drift (10% of Measureable)	8 hours	n/a
Rotational Stiffness	67.7e3 N-m/rad	35.e3 N-m/rad
Survivable Force	600 N	n/a
Survivable Moment	500 N-m	n/a

FMS
WBS 100

B/B; 110

111. System Specification
112. System Design
113. Mechanical System
114. Microprocessor System
115. Force algorithm s/w
116. Initial Testing

Non-Lin S/W; 120

121. Matlab 3 dof
122. Valid 3 dof
123. Matlab 6 dof

Pre-Com; 130

131. System Specification
132. System Design
133. Mechanical System
134. Microprocessor System
135. Force Algorithm s/w
136. Calibration Testing

Calibration; 140

141. System specification
142. System Design
143. Mechanical System
144. S/W control system
145. Neural Network Dev
146. Manufacture
147. Verification

S/W Sim; 150

151. Free Version
152. B/B update
153. Pre-Com update
154. Service version

Figure 2-1 Work Breakdown Structure

Table 2-2 Tasks for Breadboard Unit

WBS	Task Title	Task Description
110.	Breadboard Development	6 dof prototype has been built and assembled with exception of struts. It has been tested to show all 6 dof excitation is possible. Low cost instrumentation has limited identified modes to Nyquist range, but there additional modes above that range which can be used to increase performance have been noted experimentally.
111	System Spec	**Completed**
112	System Design	Mechanical – **completed**. Electronic & s/w being defined as test results become available. This will also provide the external interface definition of the system interface to the test equipment, as well as to the larger space robotic systems it will be needed for.
113	Mechanical System	Mechanical system consists of: housing, piezoceramic driving unit & accelerometers. The housing has been developed as drawings & sent out for manufacture. Poled ceramics already in-house has been installed. Computer models have been used to predict performance and are now being used to understand early test results. The early results are more favourable than had been assumed.
114	Microprocessor	Existing segmentially poled piezoceramic elements have been driven to produce distinct modes shapes at the system resonant frequencies. We have developed a 6 dof driving system (using BeagleBone) a DSP. The processing time is still slow. We continue to focus on identifying and tracking modes which represent each of the 6 force dof's.
115	Force Algorithm	Force algorithm is the conversion of frequency response functions to 6 dof force. We have an existing system of 3 dof prediction, but this will need to be revised to reflect the new breadboard h/w and accelerometer configuration. The accelerometers are used to monitor the frequency response of the resonances - including their amplitude. It is this combination of frequency and shape tracking that allows for transduction to force. Measured accelerometer shapes will be aggregated to functions reflective of the loading plate shape. The force algorithm is the s/w that acquires acc. responses and converts them into force. The acquisition portion of the Algorithm in MATLAB is largely complete. **Partially completed**
116	Initial Testing	The non-linearity of the FMS is fundamental to function. Breadboard testing is predominantly to validate the unloaded structure. This information is being used to: support data acquisition and force algorithm s/w development, and as upgrade the simulation (eventually its own commercial product). Most of the frequencies identified have only shifted a bit from FE predictions. We have determined that there are more modes available to support transduction than had been assumed (improved performance). A few, loaded configurations (mostly torsion mode) will be tested to frequency shift.

Table 2-3 Tasks For Non-Linear Analysis Software Tool

WBS	Task	Description
120	Non-linear, normal modes software module	A matlab routine to predict dynamic response of the structure under varying load conditions. It is a combination of partial differential equations of the 2 stiffening mechanisms involved near the strut connections, and then the knitting together of these results with special purpose FE models. This tool has 2 applications - to support the design and as an algorithm in the simulator product. **Completed**
121	Matlab 3 dof	Matlab routine to model the stiffening nature of the system.. **Completed**
122	Validate Matlab 3 dof	The routine software was evaluated against the existing 3 dof test data. **Completed** The test data frequency shifts are based on modes high enough to avoid b.c. sensitivity. A study of external bc sensitivity has been done: Technical Memo: Study of External Boundary Condition Influences on FMS modes. GVE-15-FMS-TM02, Jan 2016.
123	Matlab 6 dof	**Completed**; Technical Memo: Derivation of Prop Force: Small FMS, Jun 2012. GVE-12-FMS-TM01. Technical Memo: Derivation of Tension Effect: Small FMS, Oct 31, 2012. GVE-12-FMSTM02.

Table 2-4 Tasks for Pre-Commercial Unit

WBS	Title	Task Description
130	Pre-Commercialization Unit Development	The breadboard development is allowing us to correct and refine the design to meet a generic design for a space robotic force moment sensor, suitable for long duration, constrained motion robotic operations. Now that we know the physical poling concept for the piezo ceramic driving system is suitable for all 6 dof, we can refine the segment sequences to minimizing lag.
131	System Specification	To be generated based on: GVE-15-FMS-Sp01, 2015. Performance: www.goodvibrationsengineering.com/FMS.html Updates will be made on the basis of test results.
132	System Design	The overall mechanical, electronic and s/w implementation have initially defined in: Design Description Small Space Robotic Force Moment Sensor Breadboard: Phase 1, GVE-15-FMS-DD01, June 2015. This will provide the external interface definition, in the form of ICD the system will interface to systems it may be implemented in, for force moment accommodation control.
133	Mechanical System	The mechanical system consists of housing and piezoceramic driving/sensing unit. These systems have been developed as drawings, then modelled analytically. The computer models are being used in correlating modal signatures to force transduction modes, and will be used to establish verification criteria from measured test data, and to support end item calibration data sheets. The details of incorporation of the struts will developed on the basis of breadboard system results. Strut tensioning conditions will be assessed.
134	Microprocess, s/w & electronics	The segmentially poled piezoceramic elements are excited by a Beagle Bone Processor. We are still experimenting with various excitation sequences on the breadboard, and that will continue, probably all through testing and calibration.
135	Force Algorithm	The force algorithm will be upgraded from the b/b matlab force algorithm software that uses acquired accelerometer responses to piezoceramic oscillation and converts them into force information. This algorithm will be modified to meet mechanical characteristics of the precommercialization unit, as well as upgraded from the breadboard MATLAB s/w , to a faster processing language.
136	Calibration + Thermal Testing	The non-linear function of load vs frequency will be experimentally defined, with measured data along the 6 dof forces involved, as well as influence of coupling between degrees of freedom. This testing sequence will include thermal conditions (unit temperature changes, as well as thermal gradients across the sensor) to illustrate the sensitivity of the system to boundary condition changes. The calibration testing will be supported by a special purpose test rig. It is possible that a neural network analysis may assist in reducing the testing time needed.

Table 2-5 Tasks for Calibration Test Design & Rig

WBS	Task Title	Task Description
140.	Calibration	The calibration test rig will have 2 roles • Initial development of the non-linear sensor • As a calibrator for each sensor built. The rig must be capable of allowing for rapid load applications, up to significant levels (safety is an issue). There will be many load applications. A review of the potential of neural networks to minimize the number of required test sequences will be performed. The system may have to be capable of specifically applying a defined set of independent loads, as well as defined coupled loads. It will be necessary to have an accurate means of determining the load levels that are being applied. It will also be necessary to have a means of applying thermal loading conditions to the FMS unit (breadboard and pre-commercialization)
141.	System Specification	The test rig performance goals and physical configuration will be defined, for design and for performance evaluation.
142.	System Design	The mechanical, electronic and s/w implementation will be defined.
143.	Mechanical System Design & Analysis	The mechanical system will consist of a secure grounding interface, a means of quickly applying and changing out the applied loads and a means of verifying amplitude of the applied loads. These systems will be developed as drawings, to be sent out for manufacture and as computer models, to evaluate prospective performance characteristics, and to verify safety margins. The computer models may also be used in establishing verification criteria for the applied loading levels. The test rig mechanical system components will be sent out for manufacture and then be integrated. The system will be designed to allow for the addition of some simple thermal loads - either convective or radiation.
144.	Software & Electronics	The loads being applied may be based on physical weights, or on actuators, or a combination. A trade off of the feasibility of these options will define how much electronics will actually be needed. The software will also include a means of verifying the load level being applied to the FMS. It must also be capable of applying pure loading dof , as well as selected coupled loading dof.
145.	Neural Network Dev	The non-linear nature of the FMS makes combined loading cases particularly difficult to consider. Evaluation of the use of neural network algorithm will be performed to minimize the number of high load level tests that must be performed
146.	Manufacture & Integration	Some of the test rig mechanical system components will be sent out for machining, some will be directly procured, others produced in-house. They will be integrated in-house.
147.	Verification	Load level application of the test rig will be validate the design.

Table 2-6 Tasks for Simulator Software Development

WBS	Title	Task Description
150.	Simulator s/w	A software system to simulate the FMS which accepts commands from a robotic control system, and provides information back to it is needed to allow customers to develop their space robotic control system, in advance of hardware implementation. A matlab version has been written. A review of elements of input and output requirements of interest to controls engineers will be undertaken.
151.	Free version	s/w simulator that allows for simple interface to imbedded hardware that the FMS will be used in. This initial simulation will only be partially validated (against available test data). Placed executable on web page. The 2nd version, incorporating thermal errors generated from sun on housing has been **Completed.**
152.	B/B update	upgrade initial simulator as b/b test data becomes available. This version will be used to support in-house consulting services related to potential FMS app's.
153.	Pre-Com Unit; update	update b/b simulator versions to reflect actual precommercialization unit test results
154.	Service Version	upgrade pre-commercial unit simulation to for sale to FMS customers

2.3 Project Schedule

Figure 2-2 is a summarized GANTT chart and Figure 2-3 provides a detailed version of current efforts.

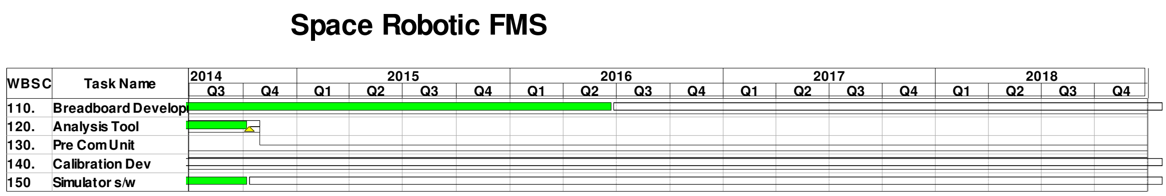
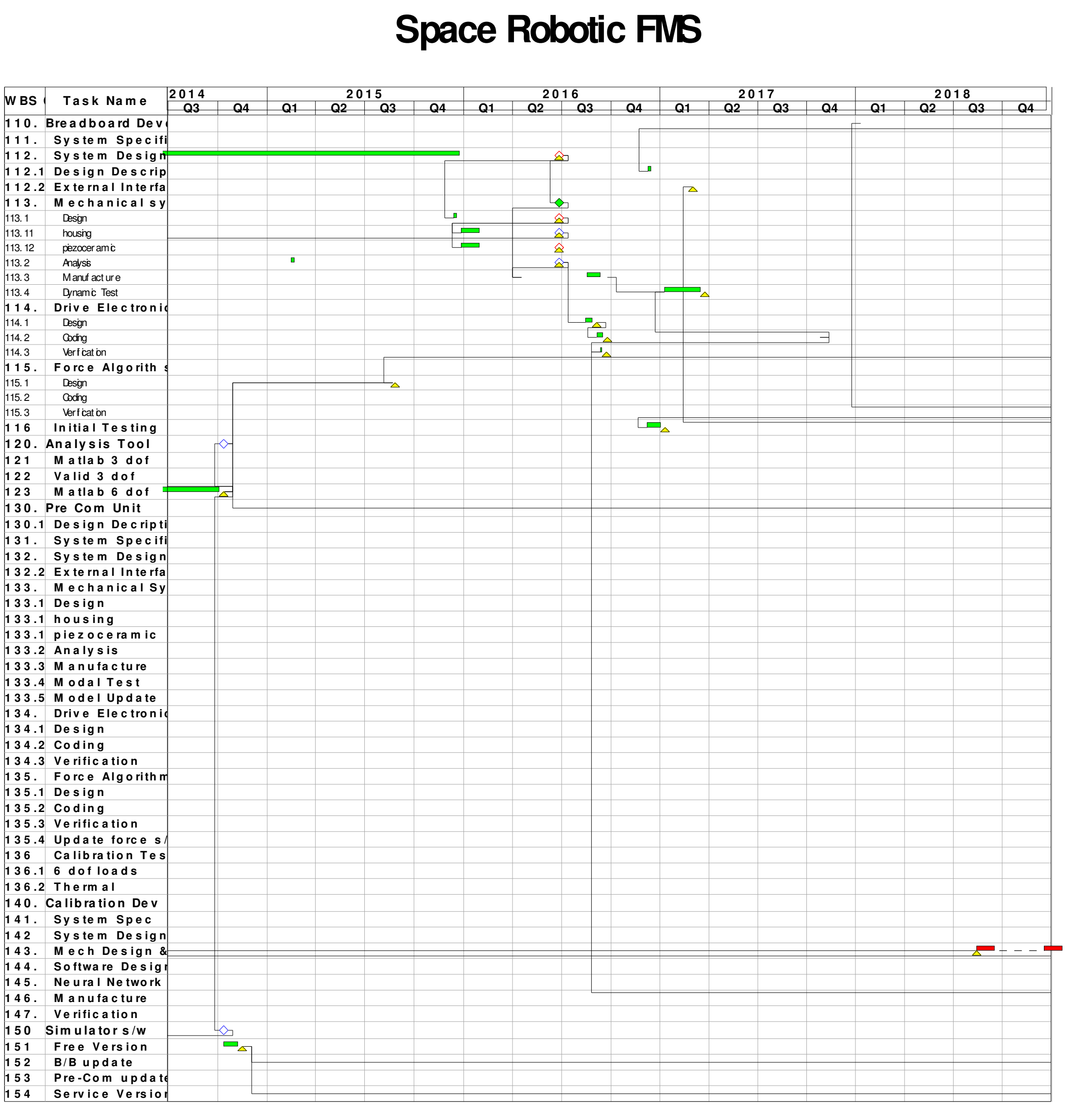


Figure 2-2 Summarized GANTT Chart

Figure 2-3 Detailed GANTT Chart



2.4 Cost Breakdown

WBS	Task	Labour	To Be Completed	
			Labour	Material
110	Breadboard Unit	858,600	343,440	10,000
120	Non-linear Analysis Tool	961,920	0	0
130	Pre Commercialization Unit	932,600	932,600	17,000
140	Test Rig	705,600	705,600	300,000
150	Simulator software	1,954,200	104,000	-
	Total		2,412,640	

2.5 Anticipated Net Cash Flows by Calender Year

WBS	2017	2018	2019	2020	Thereafter
110	-110,000	-200,000	-43,440	0	0
120	0	0	0	0	0
130		-150,000	-300,000	-300,000	-199,600
140		-20,000	-300,000	-500,000	-185,600
150		-52,000		-52,000	0
Production Unit				-185,000	-400,000
Unit Sales				250,000	4,000,000
SRED	17,000	17,000	257,000	340,000	44,000
IRAP		50,000	50,000	50,000	
Sim Income			80,000	80,000	80,000
Sum	-93,000	-355,000	-256,440	-317,000	3,266,800

2.6 Project Location

The breadboard stage of work will be done within limited office facilities at 12585 Weston Road, King City, Ontario. The calibration rig and full range testing will need more space, at least a 4m x 4m x 3m dedicated lab space.

The machining efforts needed for both the test rig and FMS development units will continue to be subcontracted out to two of the local machining groups we currently work with.

3.0 Company Capability

3.1 Management

Good Vibrations Engineering Ltd. has been combining their consulting engineering work (structural, thermal for space and geophysical developments) with in-house technology development projects since the company began operation in 1992. The company has reinvested all possible capital into development projects, all with an element of space focus. We have been ready for the space world to return interest to ISS, to an eventual Mars destination and to develop commercial robotic endeavours.

Sherry Draisey managed 12 engineers, while she was manager of Canadian Space Station Project Structure group at the former Spar Aerospace. During the 90's, GVE's reached a staff size of 6. Sherry's long term obsession with people has resulted in a strong intelligence network in the North American space sector.

Mayes Mullins, also a former Spar employee, had a maximum staff of 90 while he was Manager of Mechanical Engineering. While Mayes is certainly capable of management of larger projects, his preference is in the technical area - and that will be his role in this project.

During the 90's Sherry also acted as a technical consultant to Canada Revenue Agency's SR&ED program - which has given her expertise in that program which assists cash flow issues for new developments.   In a short career, prior to engineering, Sherry's job as a pension clerk at London Life gave her a better respect for the importance of administration than is normally for an engineer.

One of Good Vibrations Engineering Ltd. management developments is our 'virtual boss'. 'He' has already focused our work to understanding of the better than expected test results from the mechanical configuration of our FMS system. Often, a boss or direct customer is needed to provide adequate motivation for difficult tasks and decisions. In the absence of such a figure, we have developed a 'virtual boss'. The concept is consistent with the 'open' applications that are unfolding. Our 'virtual boss' consists of placing this development plan on the web, and publishing a monthly report on the web (www.goodvibrationsengineering.com/mth_rpt.html) , reporting progress. So far, this has been amazingly useful. We anticipate it has the additional advantage of providing a market outreach to prospective customers. We have noted about 1-2 hits a day on our monthly report - international.

3.2 Technical

Sherry and Mayes have kept abreast of technology, partially through their consulting work, but also through active participation in technical conferences and journals.
They are both particularly capable in the project proposed:

- have extensive space robotic experience (Canadarm's), particularly in the area of structural dynamics (modal analysis).
- current geophysical consulting work is very similar in application to the test rig needed for the calibration of the FMS.
- The piezoceramic sensing element needed for the FMS is similar to a former project they developed for the DND lab in Halifax (ultrasonic destruction of micro organisms), and later applied as a project for the European space agency.
- built and tested two earlier space robotic FMS prototypes. The most successful based on the piezoceramic transduction method proposed here.
- engineering simulator developments for mechanical applications; example of 3 included on our web pages

Our proposed project is an extension of work initiated by Sherry while she worked at Spar. The patent was eventually turned over to her, after she left the company. She furthered the development of the concept through an IRAP project and subsequently with a European space agency (ESA) study.

A second patent was awarded last year.

In the last five years, we have completed analysis of the ESA funded FMS test data, used it to design, analyse and build the 6 dof sensor. We have begun testing of the partially assembled 6 dof sensor. The results so far are more favourable than we had assumed. The 6 dof sensor analysis has been simulated in matlab, which is available on our web page (www.goodvibrationsengineering.com/FMS_SIM.html . The simulation will be upgraded as test results become available.

3.3 Financial capability

Good Vibrations Engineering Ltd. is solely owned by Sherry Draisey, and has no debt, beyond a shareholder loan (~$130,000).

3.4 Financial Status

3.4.1 Projected Financial Statements

	Column1	2017	2018	2019	2020	2021	2022
On-hand		9100	1600	32100	22660	660	4660
Cash Receipts:							
Loan			300000			50000	
Equity			100000	300000	150000		
CRA SR&ED		17500	17500	257000	340000	44000	44000
IRAP			50000	150000	50000		
Shareholder loan					100000		
Simulator Sales			10000	25000	80000	80000	80000
FMS Sim Cons			5000	10000	25000	25000	50000
FMS Sales					250000	375000	4000000
other sales		100000	100000	150000	150000	150000	100000
	Sum	126600	584100	924100	1167660	724660	4278660
Dispursements:							
Long Term Debt							35000
R&D		28000	422000	643440	852000	110000	110000
Marketing		5000	20000	20000	20000	100000	100000
Operations		5000	20000	48000	100000	100000	200000
patent fee							5000
Tech Consulting		85000	85000	5000	10000	10000	10000
Manufacturing		2000	5000	185000	185000	400000	1000000
	Sum	125000	552000	901440	1167000	720000	1425000
Taxes		0	0	0	0		1000000
Ending Balance		1600	32100	22660	660	4660	1853660

Table 3-1 Numbers represent dollars.

3.5 Cost tracking / accounting system

Cost and schedule will be tracked using our Scitor Project Scheduling software.

3.6 Business plan

Our business plan is available under separate cover. It includes this project, as well as our other products and services, including our vestibulator product, which we have been exporting to the U.S and Europe for almost a decade. We are anticipating our first Asian order imminently.

Production of each FMS will be done with the same in-house team as is needed for this R&D exercise. Each unit will take on the order of 6 months to 1 year to produce - because of the sensitivity to calibration issues.

The unit size is quite small (< 5 kg, <1000 cm 3) so there are no significant storage challenges. Only the test rig takes up any significant space. Machining will continue to be subcontracted out locally.

Distribution issues for small size, small volume products are limited. There will be times when we package and ship with a courier, and other times when a staff member will personally deliver the device to the customer, to help with its integration.

3.6.1 Preliminary market analysis

Table 3-2 provides a preliminary market analysis of the concept. It is difficult to establish all market analysis for a product that is not yet available, and is needed by aerospace groups - they are rather secretive.

Question	Answer
Market Definition	Civilian aerospace (Canada, NASA, JAXA, ESA) American Military
Companies in the market	JR3, ATI - not suitable for space needs MDA, Motiv Space Systems - have shown interest as a partner to us
Are other companies servicing this market with similar product?	no
Is the market saturated or open?	open - no device has proved adequate yet
Market size: 1) FMS hardware 2) FMS simulator software 3) FMS simulation consulting	 1 space unit per year; 2-4 equivalent for test beds 2–5 systems per year 1-2 contracts per year
Is it a growing market?	yes - has been slowly
How do I reach this market?	internet, technical conferences, web virtual boss and matlab simulator, available on-line;
How do competitors reach this market?	no competitors
What do customers expect for this product?	a proven system with clearly defined requirements
What core competencies must product have?	operate in space environment with wide range of thermal conditions. Support operations over long periods (hours, at least)
What are customers willing to pay? 1) hardware 2) FMS simulator 3) FMS Consulting	 not established. The 1980's NASA demo cost $4 M not established - possibly $80,000 per unit probably < $50,000 per contract
What is my competitive advantage?	low drift; simulation of capabilities available free on-line

Table 3-2 Market Analysis Table

The key commercial risk is in unit pricing. Though we anticipate being the sole supplier, the cost of the technology may delay its implementation into the systems which it will support.

4.0. Benefits to Canada

It's no longer clear that benefits to Canada are significant, but I'll list them anyway.

4.1 Technological innovation

The challenge of solving the space robotic force moment sensor is significant, in spite of the fact that it's a product that is at least a decade overdue. Google on 'space robotic force moment sensor' and there's lots of information of interest to Canada, on the first page. Our FMS concept paper is the 2nd hit down. A quote from MDA about Dextre. Here's the quote:
"Probably the most important thing in Dextre is what we call the force moment sensor," explains Richard Rembala from MacDonald, Dettwiler and Associates, the renowned Canadian robotics company that has led the development of Dextre. "The sensor is located at the wrist on each arm, and this sensor really gives Dextre a sense of touch. As it's grabbing boxes, it can actually measure how hard it's pushing, how hard it's twisting. This means it can limit the forces applied to structures so it doesn't break them."

4.2 Social and economic benefits

The project we're proposing is fairly small, so the direct employment effect is small - but that employment will be long term. It is a product that will always need engineers and technicians. And it is not a product that is likely to be moved offshore for low labour cost production.

Investment returns on space products are very long term, and do not normally generate the 'hockey stick' sales curve that investors are interested in. Recent renewed interest in space from private sector could generate a immediate need for FMS – private sector cannot allow its business plan to be delayed for years, on the basis of ONE missing element.

5.0 Loan Repayment

GVE expects to begin receiving revenue from FMS unit sales in 2020. Loan repayment will begin in 2022 and substantial dividends to investors will begin to ramp up then.