Index

First Part: Context of the problem	7
General Introduction28	
1. General context28	
1.1. A brief characterization of viticulture in Chile	
1.2. Water scarcity and optimization in the efficiency of water use in the vineyard	
29	
2. Vine water consumption and vine water status	
2.1. Why phenology is an important factor to consider when irrigation management made?30	is
2.2. Water status measurements at the plant level	
2.3. Estimation of water consumption	
2.4. High resolution images for estimation of water consumption in vineyard34	
2.5. Monitoring vineyard water status using wireless sensor networks (WSN)35	
3. Objectives of the thesis	
4. Stages of research, scientific questions and definition of the problem37	
5. Bibliography38	
Second Part: Remote sensing4 Chapter 1: Using clustering algorithms to segment UAV-based RGB images44	3
Abstract44	
Introduction44	
Materials and methods46	
Experimental setup and Image acquisition46	
Greenness Index46	
Image segmentation algorithm47	
Results and discussion48	
Conclusion50	
Acknowledgements51	
Bibliography51	

	54
Abstract	52
Introduction	55
Materials and methods	55
Study site	55
Physiological measurements	56
Eddy Covariance measurements	56
Thermal and multispectral images acquisition and process	sing57
Implementation of Shuttleworth and Wallace model	58
Statistical analysis	59
Results and discussion	59
Conclusion	62
Acknowledgements	62
Bibliography	62
d Part: Spatialized wireless sensors	
d Part: Spatialized wireless sensors napter 3: Spatialized system to monitor vine phenology: To a low-cost wireless sensor network	Towards a methodolog
napter 3: Spatialized system to monitor vine phenology:	Γowards a methodolog
napter 3: Spatialized system to monitor vine phenology: To a low-cost wireless sensor network	Γowards a methodolog
napter 3: Spatialized system to monitor vine phenology: To a low-cost wireless sensor network	Fowards a methodolog
apter 3: Spatialized system to monitor vine phenology: To a low-cost wireless sensor network	Γowards a methodolo 666667
apter 3: Spatialized system to monitor vine phenology: To a low-cost wireless sensor network	Γowards a methodolo 6667
Abstract Introduction Materials and Methods Experimental site description	Γowards a methodolo
Abstract Introduction Materials and Methods Experimental site description Development of a spatialized phenological sensor	Fowards a methodolo
Abstract Introduction Experimental site description Development of a spatialized phenological sensor Micro controller.	Γowards a methodolog
Abstract Introduction Materials and Methods Experimental site description Development of a spatialized phenological sensor Micro controller. Wireless communication systems	70
Abstract Materials and Methods Experimental site description Development of a spatialized phenological sensor Micro controller. Wireless communication systems Temperature sensor	70
Abstract Introduction Materials and Methods Experimental site description Development of a spatialized phenological sensor Micro controller. Wireless communication systems Temperature sensor Data storage	70
Abstract Introduction Experimental site description Development of a spatialized phenological sensor Micro controller. Wireless communication systems Temperature sensor Data storage Charging source and power supply	Fowards a methodolo

Results	78
Climatic characterization of the experimental site	78
Validation process of the low-cost wireless sensors network	78
Spatialized study of phenology.	82
Discussions	88
Ongoing and future work	90
Conclusions	91
Acknowledgements	92
References	92
napter 4: Low-cost wireless sensor networks for monitoring spatial	variability
nter status in a commercial vineyard	99
Abstract	99
Introduction	100
Materials and Methods	103
General description of aSIMOV system	103
Experimental site	103
Experimental design	104
Measurement of micrometeorological variables	104
aSIMOV Node	105
aSIMOV Coordinator Unit	105
Communication protocol	106
Evaluation of the reference sensor and the low-cost thermometers	106
Temperature and physiological measurements	107
Crop Water Stress Index (CWSI) computation	107
Statistical analysis	108
Results	109
Discussion	118
General Considerations: Some indications based on literature	118
Specific indications: Communications and power consumption	
Stress index computations	
Final considerations	
Conclusions	122
	· · · · · · · · · · · · · · · · · · ·

Fourth part: Discussion, perspectives and general conclusions	134
General discussion and future perspectives	135
Answer to the general problem of the thesis	135
Scientific originality of the work	
Ongoing and future work	137
Fifth part General Conclusion	139
Appendix	142
Appendix 1: Invention Report 1, in presentation format for UTAL: aSIMO	V; Wireless
System for Vine Monitoring.	143
Appendix 2: Invention Report 1, in presentation format for UTAL: Telema	ap; Geo-informatic
platform for monitoring the vigor and water consumption of fruit trees and	vines163
Appendix 3: Participation in other events not reported in the document dur	ring the completion
of the Doctoral thesis	179
Appendix 4: Publication of "UAV-based estimation of vineyard actual eva	potranspiration
using the Shuttleworth and Wallace model"; International conference in Ho	rticultural Sciences
	185
Appendix 5: Publication of "Estimation of vineyard water status using infi	rared thermometry
measurement at different positions of the canopy"; International conference	in Horticultural
Sciences	186
Appendix 6: Publication of "Development of models to estimate vine water	er status using
spectral indices"; International conference in Horticultural Sciences	187
Appendix 7: Publication of "Assessment of the clumped model to estimate	e olive orchard
evapotranspiration using meteorological data and UAV-based thermal infra	red imagery";
International conference in Horticultural Sciences	188

List of figures

Chapter 1: Using clustering algorithms to segment UAV-based RGB images
Figure. 1 Raster image of groups defined through k-means algorithm
Figure. 2 where; a) Area corresponding to crop defined as a class 1 in k-means b) Area corresponding to shadow defined as a class 2 in k-means, and c) Area corresponding to soil defined as a class 3 in k-means
Figure. 3 Raster image of groups defined through CLARA algorithm
Figure. 4 a) Area corresponding to crop defined as a class 1 in using CLARA b) Area corresponding to shadow defined as a class 2 using CLARA, and c) Area corresponding to soil defined as a class 3 using CLARA
Figure. 5 where; a) UAV based image obtained with an RGB sensor b) Raster image of groups defined through k-means (purple) and ClARA (blue) algorithms. Red circles indicate pixels that correspond to the crop layer for k-means
Chapter 2: Assessment of vineyard water status using high-resolution remote sensing information in combination with meteorological data
Chapter 3: UAV-based estimation of actual vineyard evapotranspiration using the Shuttleworth and Wallace model
Figure 1. Comparisons at the time of UAV overpass over a commercial vineyard between observed (X-axis) and estimated (Y-axis) values of Rni = Instantaneous Net Radiation; Gi = Instantaneous Soil Heat Flux; LEi = Instantaneous Latent Heat Flux
Chapter 4: Spatialized system to monitor vine phenology: Towards a methodology based on a low-cost wireless sensor network
Figure 1. Experimental site and system location
Figure 2. Voltage regulator board
Figure 3. Schematic model of data transfer

- **Figure 4.** Absolute value of the differences in days, with respect to the measured value for estimates made during season 1 (2011-12). The orange color indicates the measurement points at which values greater than 4 days were observed, on the other hand, the points indicated with yellow indicate differences less than 4 days between observed values versus estimated. a): corresponds to an estimation of phenology made using (Ortega-Farías et al., 2002) model in combination with spatialized sensors (SEN-ME), b): is the estimation of phenology made using (Ortega-Farías et al., 2002) and meteorological weather station (AWS) data (AWS-ME), c): is the estimation of phenology made using (Parker et al., 2013) model in combination with spatialized sensors (SEN-GPV) and d): is the estimation of phenology made using (Parker et al., 2013) and meteorological weather station (AWS) data (AWS-GPV).. 83
- **Figure 5.** Absolute value of the differences in days, with respect to the measured value for estimates made during season 2 (2012-13). The orange color indicates the measurement points at which values greater than 4 days were observed, on the other hand, the points indicated with yellow indicate differences of less than 4 days between observed values versus estimated. a): corresponds to an estimation of phenology made using (Ortega-Farías et al., 2002) model in combination with spatialized sensors (SEN-ME), b): is the estimation of phenology made using (Ortega-Farías et al., 2002) and meteorological weather station (AWS) data (AWS-ME), c): is the estimation of phenology made using (Parker et al., 2013) model in combination with spatialized sensors (SEN-GPV) and d): is the estimation of phenology made using (Parker et al., 2013) and meteorological weather station (AWS) data (AWS-GPV).. 84

Chapter 6: Low-cost wireless sensor networks for monitoring spatial variability of plant water status in a commercial vineyard

Figure 1. Meteorological conditions for season 2017-18 (September 1 to March 30), where ETc corresponds to reference evapotranspiration (mm d-1), Rs is solar radiation (W m-2), and
DOY is the day of year
Figure 2. Calibration of the Apogee sensor and low-cost thermal sensor integrated in aSIMOV using a Blackbody (BB) at different temperature levels
Figure 3. Comparison per treatment of the temperature measured by MI-2H0 and aSIMOV at the same time of physiological measurements. The dotted line corresponds to 1:1 111
Figure 4. Comparison between temperatures per Level and day of year (DOY) measured by aSIMOV and MI-2H0
Figure 5. Stem water potential (SWP) measurements per treatment obtained with a pressure chamber
Figure 6. Difference of Tc-Ta versus Stem Water Potential (SWP) estimated using a) MI-2H0 sensors and b) Asimov sensor
Figure 7. Relation determined between Crop Water Stress Index (CWSI) and Stem water potential (SWP)
Figure 8. Stem water potential (SWP) measured and modeled with aSIMOV

List of tables

Chapter 1: Using clustering algorithms to segment UAV-based RGB images
Chapter 2: UAV-based estimation of actual vineyard evapotranspiration using the Shuttleworth and Wallace model
Table 1. Physiological measurements carried out during the 2018-2019 growing season.60
Table 2. Validation of sub-models that compute LEi = Instantaneous Latent Heat Flux, Rni = Instantaneous Net Radiation, Gi = Instantaneous Soil Heat Flux, ETa= Daily evapotranspiration, over a commercial vineyard at the time of UAV overpass61
Chapter 3: Spatialized system to monitor vine phenology: Towards a methodology based on a low-cost wireless sensor network
Table 1. Technical characteristics Xbee Pro 63mW RPSMA - Series 2B73
Table 2. Error estimators for estimates made during the two study seasons
Table 3. Absolute value of the differences in days, with respect to the measured value for estimates made during two study seasons. 80
Table 4. Coincidence expressed in percentage between the values measured in the field and those estimated using both models 82
Chapter 4: Low-cost wireless sensor networks for monitoring spatial variability of plant water status in a commercial vineyard
Table 1. Validation of dataset obtained from MI-2H0 and low-cost aSIMOV sensors111